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Bureau of Economic Geology and Technology

J. A. UDDEN, Director

Review of the Geology of Texas

BY

J. A. Udden, C. L. Baker, and Emil Böse

THIRD EDITION
(REVISED 1919)

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FOREWORD TO THE THIRD EDITION OF BULLETIN NO. 44

In presenting to the public this third edition of our Bulletin 44, I wish to express my high appreciation of the generous cooperation and assistance given by the three former members and co-authors of this report, Prof. C. L. Baker, Dr. Emil Bose, and Lieut. E. L. Porch. Though their immediate interests no longer lie with this Bureau, they have given freely of their time and labor in suggesting and advising upon corrections and alterations in the matter contained herein. I wish also to thank our secretary for the careful work done in connection with the editorial work upon this report, and preparation of the index.

New facts are coming to light constantly. Cognizance cannot be taken of many of these in a review such as this, but it is necessary from time to time to make alterations demanded by local surveys as the work of mapping additional counties progresses. Some changes on the geologic map will be noted in Terrell and Val Verde counties. Other small changes will be found in Taylor and Runnels counties. A few slight changes have been occasioned by information received from geologists working for private companies. Some alterations and additions have been made in the illustrations. Changes have also been found necessary in the text, and additional matter has been introduced on subjects that seem to need more attention than given to them before.

For future editions, the Bureau will be very grateful to receive any suggestions and corrections offered by geologists working in the State. Cooperation of this kind will be most highly appreciated.

J. A. UDDEN.

Austin, Texas.
May 22, 1919.

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INTRODUCTORY

By J. A. Udden

The purpose of this paper is to present to the public a review of what is so far known concerning the geology of the State of Texas. During the last sixty years this subject has been studied by a number of individual investigators and by several surveys; Federal as well as State organizations. The results have been published through various channels, private and public. No attempt has recently been made to summarize the data thus made known. The present paper is an effort to give a brief, systematic account of the main facts ascertained relative to the rocks in Texas, and their economic, tectonic, and historic relations.

The map accompanying the report is the first of its kind for this State. The scale of the map, as well as the present state of knowledge of the geology of Texas, makes it certain that many details, if not even some of the more important items which the map presents, will be considerably modified after our knowledge of the subject has been increased by future work. Many small details have necessarily been left out on account of the scale of the map. Other details have been omitted for the want of information on the surficial distribution of some formations over various areas of the State. In the area of the Paleozoic rocks in the north half of Brewster County there is a region which will require very detailed mapping on a large scale, to differentiate the several Paleozoic formations correctly. The areas designated as underlain by Cambrian-Ordovician rocks in this region must be considered as more or less schematically treated on the map. The same may be said with regard to the delineation of some of the Paleozoic rocks in Presidio County, and particularly in the region of the Eagle Mountains in Hudspeth County. This is to some extent also true of the pre-Cambrian, Cambrian-Ordovician, and Pennsylvanian areas in Blanco, Gillespie, Mason, McCulloch and San Saba counties. Probably the least accuracy has been attained in the treatment of the Pliocene and the Pleistocene. The data necessary for the reference of some deposits to their right place in this part of the geologic column have not yet been procured. Such data are sometimes acquired through fortuitous finds of fossil-bearing beds. All deposits later than Cretaceous have thus been represented by one single shade of color in the Llano Estacado.

With all these unavoidable defects, it is nevertheless believed that the map as well as the text will prove valuable to anyone interested in the geology of the State, and that the great need of a brief exposition of the outlines of Texas geology will warrant this Bureau in facing such criticism as may be justly made of the methods it has been judged necessary to adopt in dealing with various questions, the correct solution of which can only be attained by patient search, for many years to come.

A brief statement of what has been accomplished in the study of the geology of the State up to the present time seems pertinent.

The first important contribution to the geology of Texas was made by Dr. Ferdinand Roemer of Bonn, Germany, who made extensive observations in the central part of the State in 1845, 1846 and 1847, and who later published, in Germany, the first map showing the superficial distribution of some of the formations in the State. In 1852, Dr. G. G. Shumard accompanied Captain R. B. Marcy on an exploring expedition which led him to the northern part of the State and enabled him to identify the Carboniferous along Red River, and to note the gypsum-bearing redbeds farther west. The region along the Rio Grande was explored by

Major W. H. Emory, the following year, when he conducted the Mexican Boundary Survey. In 1853, Jules Marcou took notes on the geology along a route across the southern part of the Panhandle, and near the Red River farther east. These notes were later published by the Federal Government, in the reports of the Pacific Railroad surveys. In 1858, Dr. B. F. Shumard was appointed State geologist, and served in this capacity until 1860. He made detailed surveys of Burnet and Rusk counties, and made preliminary observations over more extensive areas. Together with his brother, Dr. G. G. Shumard, who had accompanied some of the Federal exploring expeditions in the preceding years, he discovered the existence of the Permian in the Guadalupe and the Delaware Mountains.

During the six years of its existence, the Geological Survey of Texas, organized by E. T. Dumble in 1888, added greatly to our general knowledge of the geology of the State. Cummins delineated for this survey the outlines of the formations in the north and northwest part of the State. Hill, Taff and Leverett mapped the north-central and the northeast part of the State. Kennedy mapped in detail several counties in the eastern half of the State, and made important contributions to our knowledge of the Tertiary sediments and their economic contents. Drake mapped the formations in the Colorado coal field, and Comstock traced the outlines of the geology of the Central Mineral Region. Contributions were also made to the areal geology of the gulf coastal region, and of the region west of the Pecos.

The University Mineral Survey, organized in 1901 by Dr. W. B. Phillips, while devoting its energies mainly to economic subjects, also made some contributions to areal and stratigraphic geology. B. F. Hill and J. A. Udden mapped the more important formations in the mountainous region from west of the Carmen Range to El Paso south of the Southern Pacific railroad. In co-operation with the United States Geological Survey, Richardson mapped the region west of the Pecos and north of the Texas and Pacific Railroad.

The most important contributions to the areal geology of Texas made by the United States Geological Survey are Hill's report on the geology of the Black and Grand Prairies, covering the central and north-central part of the State; the Austin folio and the Nueces folio by Hill and Vaughan;

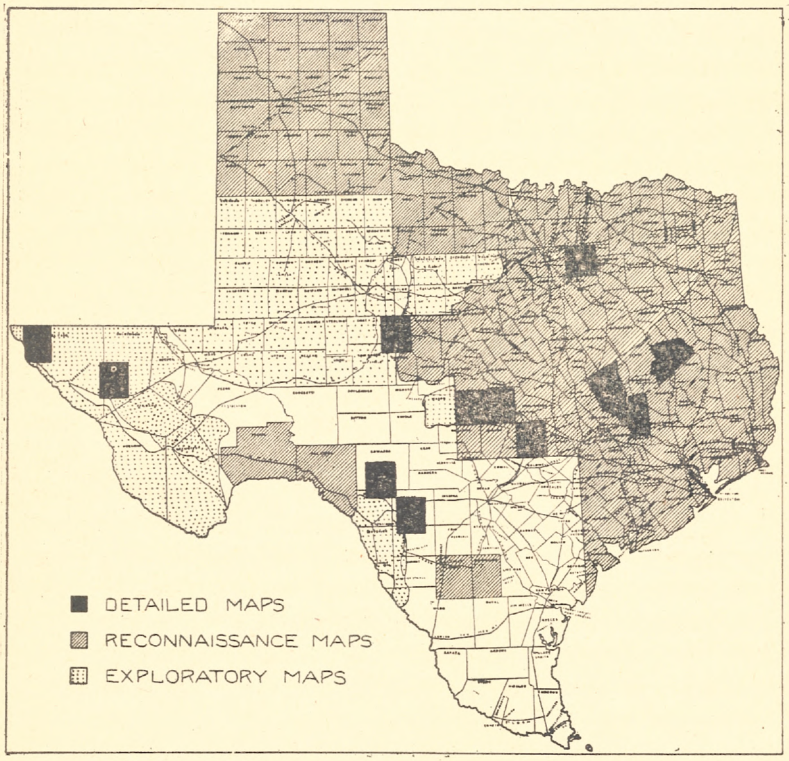


Figure 1.—Map showing the areas in Texas which have been geologically mapped in detail, by reconnaissance, or by exploratory surveys, prior to 1919, showing only maps which have been published.

the Uvalde folio by Vaughan; the El Paso and the Van Horn folios by Richardson; the Llano-Burnet folio by Paige; two papers on the water resources of the Panhandle, by Gould; a paper on the geology and underground water resources of northern Texas, by Gordon; a paper on the oil fields of the Texas-Louisiana Gulf Coastal Plain, by Hayes and Kennedy; a paper on the geology and underground waters of the southeastern part of the Texas Coastal Plain, and another paper on La Salle and McMullen counties, both by Alexander Deussen.

In 1907 Augustana College published a report and map by Udden of the geology of the lands adjoining the Rio Grande in Val Verde, Kinney, Maverick, and Webb counties.

Recently the Bureau of Economic Geology and Technology has made reconnaissances in the region west of the Pecos between the Texas and Pacific and the Southern Pacific railroads, and also in the Paleozoic area around Marathon. The results of these reconnaissances are incorporated in the review here presented.

The areal distribution and a rough classification of geological work so far accomplished in the State may be further elucidated by a brief review of the most important geological mapping done up to the present time.

Only a small part of the domain of Texas has been mapped with fairly sufficient detail. About 7,188 square miles have been mapped in detail by the United States Geological Survey, about 3,424 square miles by the Geological Survey, Texas, organized by Dumble, and a small area mapped by this Bureau. This makes about 12,000 square miles in all, mapped in detail; or about one-twenty-fifth part of the entire area of the State. The location of these fairly satisfactorily mapped areas is indicated on the accompanying sketch map (Fig. 1) and specified in the following table:

Table showing the number of square miles in Texas mapped in fair detail

	Area in sq. miles
Maps published by the U. S. Geological Survey:	
Nueces Folio, by Hill and Vaughan, 1898	1,035
Uvalde Folio, by Vaughan, 1900	1,040
Austin Folio, by Hill and Vaughan, 1902	1,030
El Paso Folio, by Richardson, 1909	1,014
Llano-Burnet Folio, by Sidney Paige, 1912	2,050
Van Horn Folio, by Richardson, 1914	1,019

	Area in sq. miles
Maps published by the Geological Survey of Texas:	
Houston County, by Kennedy, 1891	1,231
Grimes, Brazos and Robertson Counties, by Kennedy, 1892	2,193
Map published by Bureau of Economic Geology:	
Dallas County, by Shuler, 1919	900
Total area covered by detailed maps	11,500

Most of the geological mapping so far done in the State may be characterized as reconnaissance mapping. The Geological Survey of Texas mapped some 15,220 square miles, mostly in the central part of the State. In these maps, especially in the map made by N. F. Drake, many details appear, but the area covered necessitated the adoption of small scale maps. The same may be said about several maps published by the United States Geological Survey, covering areas varying from 3,700 to 32,600 square miles. Some of these maps overlap each other and also overlap regions worked by the Geological Survey of Texas. In part they are reproductions of the maps previously published, and modified so as to serve the purpose of various reports on special subjects or areas.

Table showing the number of square miles in Texas mapped by reconnaissance work

	Area in sq. miles
Maps published by the Geological Survey of Texas:	
Map of the Cretaceous area north of the Colorado River (south part), by J. A. Taff and S. Leverett, 1892	2,630
Map of the Colorado Coal Field, by N. F. Drake and assistants, 1892	4,000
Map of the Cretaceous area north of the Colorado River (north part), by J. A. Taff and S. Leverett, 1892	8,590
Maps published by the U. S. Geological Survey:	
Map of the Black and Grand Prairies of Texas, by R. T. Hill, 1898 (not including territory mapped by Taff and Leverett)	32,600
Map of Northeast Texas, by C. H. Gordon, 1911 (not including area previously mapped by Hill in 1899)	3,699
Map of a portion of the Gulf Coastal Plain, by Wm. Kennedy, 1903 (not including the territory previously mapped)	19,000

	Area in sq. miles
Map of the eastern portion of the Panhandle of Texas, by C. N. Gould, 1906	10,800
Map of the western portion of the Panhandle of Texas, by C. N. Gould, 1907	9,360
Map of portions of Louisiana, Texas, and Arkansas, G. D. Harris, 1910 (not including areas previously mapped)	6,000
Sketch map of the Wichita region, by C. H. Gordon, 1913 (not including territory previously mapped)	10,500
Map of Texas, east of the 97th meridian, by A. Deussen, 1914 (not including areas previously mapped)	4,000
Geological map and section of LaSalle and McMullen counties, by A. Deussen	2,887
Maps published by the Bureau of Economic Geology:	
Map of Runnels County, by J. W. Beede and V. V. Waite, 1918	1,083
Map of Val Verde County, by John R. Roberts and J. P. Nash, 1918	3,083
Map of Terrell County, by D. D. Christner and O. C. Wheeler, 1918	2,635
Total areas covered by reconnaissance maps	120,867

Considerable exploratory mapping was done by the Geological Survey of Texas. The reconnaissance map of the Staked Plains, made by Cummins in 1891, covered 27,300 square miles, and the field work in this area was done in one season. Another map, made by Cummins, tentatively located the lines of outcrop of the Cisco and the Canyon coals and the east limit of the Permian in the north-central part of the State. A map made by Comstock of the Central Mineral Region was of this class. All of these were important advances of geological knowledge in their day.

We may class as exploratory surveys, also, most of the mapping done in the western part of the State by the University of Texas Mineral Survey. The geological work done on these maps was by necessity confined to delineating general outlines only.

The exploratory maps cover about 58,905 square miles, or less than one-fifth of the area of the State.

In 1914 Udden mapped the Glass Mountains and in 1915 Baker and Bowman mapped a large area to the south and to the northwest of these mountains. Some of this mapping might well be classified as reconnaissance work.

Table showing the number of square miles in Texas mapped by exploratory work

	Area in sq. miles
Maps published by the Geological Survey of Texas:	
Map of the central mineral region, by Theo. B. Comstock in 1890 (not including the areas subsequently mapped by the United States Geological Survey)	1,300
Map of the coal-measures and Permian, by Cummins (in north-central Texas)	4,679
Map of the Staked Plains and adjacent area, by W. F. Cummins and N. F. Drake, 1891	27,300
Maps published by the University of Texas Mineral Survey:	
Maps of Trans-Pecos Texas, north of the Texas and Pacific Railway, by G. B. Richardson, 1903	9,000
Map of the Shafter area, by J. A. Udden, 1904	456
Map of part of West Texas, south of the Southern Pacific Railroad, by B. F. Hill and J. A. Udden, 1904	8,000
Map published by Augustana College:	
Map of the lands belonging to the New York and Texas Land Company, Ltd., in the Upper Rio Grande embayment, by J. A. Udden, 1907	3,000
Map published by the Bureau of Economic Geology:	
Map of the Glass Mountains and the Front Range, by J. A. Udden, C. L. Baker, and W. F. Bowman	5,170
Total area covered by exploratory maps	58,905

Taken together, these three classes of maps cover an area of 191,272 square miles. There remain, therefore, 81,126 square miles, or nearly one-third of the entire area of the State on which no maps have yet been published. Most of this territory extends in a broad belt from Jeff Davis County southeastward to the Gulf. (See Fig. 1.)

In the preparation of this bulletin we have drawn upon many sources of information, due credit for which is given in the text. Our especial thanks are due to the United States Geological Survey and its director, Dr. George Otis Smith, who has kindly furnished various unpublished data, bearing on the Tertiary in the southern part of the State.

We also extend our thanks to Dr. E. T. Dumble, chief

geologist for the Southern Pacific Railroad, who has placed at the disposal of the Bureau various information relative to the classification and the areal distribution of the Tertiary and later formations, and who has kindly read and criticised that part of the text treating of the same formations.

The Bureau is likewise under obligations to Prof. Alexander Deussen, consulting geologist, whose work on the Tertiary in the southern part of the State, done for the United States Geological Survey, enabled us to map also this part of our domain.

CHAPTER I

PHYSIOGRAPHY

By C. L. Baker

Physiography aims to give a correct description and rational explanation of the origin of land forms, such as valleys, plains, mountains, or other relief features, large and small.

The surface features of the State of Texas are mainly the result of erosion and of ground movements due to what are known as tectonic (land- and mountain-building) forces. Some minor features are also due to sedimentation by water and to sedimentation and erosion by winds. Climatic conditions naturally largely determine erosion and sedimentation in the atmosphere as well as in terrestrial waters, and in this way they have a determining influence on land forms.

It is to the tectonic forces that we must ascribe the making of the larger physiographic features of the State, such as the main elevated regions to the northwest, and the extensive low-lying area in the vicinity of the Gulf. We may include among the tectonic forces, also, the orogenic or mountain-building forces that have produced minor uplifts and many folds and fractures in various parts of the State. No part of the surface relief in Texas is due to the accumulation of glacial deposits, which are common in the northern part of the United States. It may also be stated that no part of its present surface is the direct result of superficial volcanic activity.

Almost all the minor relief in this State is the result of erosion acting upon rock masses of a great variety of structures and of all degrees of resistance to the forces of erosion. As climatic changes as well as changes in the rocks now forming the surface are more or less gradual, as we pass from one part of the State to another, we quite naturally find that the physiographic divisions which can be distinguished as typical of different parts of the State in many cases merge gradually into each other in intervening regions, so that the limits between different regions cannot always be accurately defined. Orogenic or mountain-building forces, on the other hand, usually produce radical changes in relief, the boundaries of which are clearly outlined.

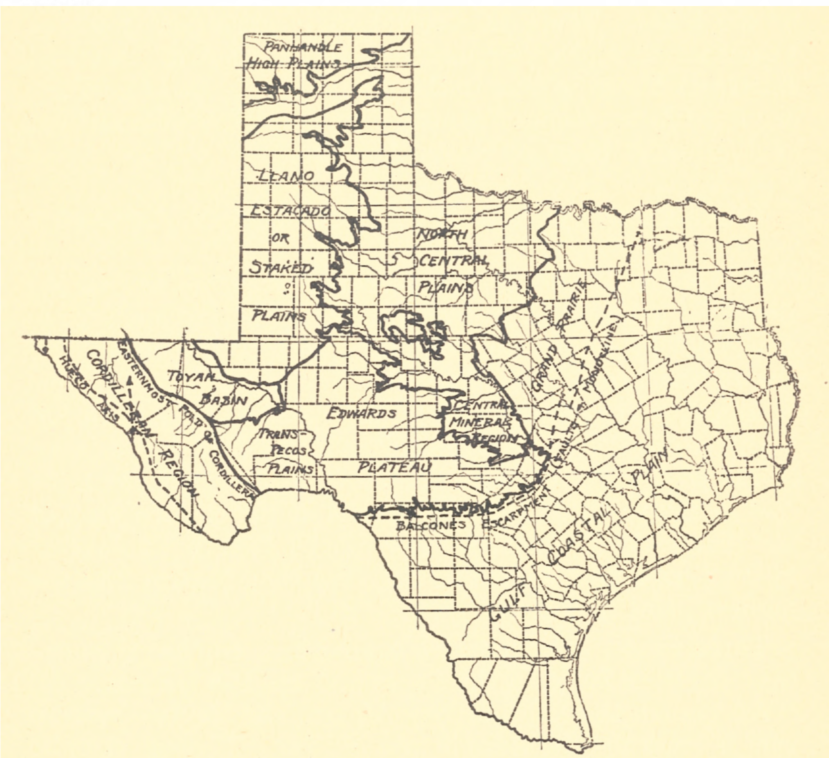


Figure 2.—Sketch map showing the principal physiographic regions of Texas.

In describing the physiography of Texas it will be most convenient to set forth and discuss the features which characterize three principal land forms that are primarily the result of tectonic forces.

MAIN PHYSIOGRAPHIC REGIONS

Three of the great physiographic provinces of North America extend into Texas and together they make up its area. These are the Great Plains, the Atlantic and Gulf Coastal Plain, and the Western Cordillera or Mountain System. None of these physiographic provinces is confined to the State. The Gulf Coastal Plain stretches from the peninsula of Florida around the gulf to Central America; the Great Plains extend to the Arctic Ocean; and the Western Cordillera reaches the northern shore of Alaska and the southernmost point of South America.

TRANS-PECOS PORTION OF THE CORDILLERAN PROVINCE

The western half of Trans-Pecos Texas belongs to the Cordilleran province. This is a region of low mountains separated by plains and basins. Most of the mountains are of the broad, somewhat flat, plateau type. For this reason they are sometimes regarded as being a part of what is called the Colorado Plateau Province. The range in altitude of the Trans-Pecos Mountain Region is from 1,500 feet in the valley of the Rio Grande at the eastern base of the Sierra del Carmen, to about 8,690 feet in El Capitan in the Guadalupe Mountains near the New Mexico line, the highest point in Texas.

Three ranges of mountains extend in a northwest-southeast direction between the Pecos and the Rio Grande. All three run northward into New Mexico and the two eastern ranges cross the Rio Grande into Mexico. Through the two eastern ranges the Rio Grande cuts a series of canyons. This indicates that the river was in existence before the mountains were uplifted athwart its course.

The westernmost range, the Franklin Mountains, continues northward into the Organ and San Andreas ranges of New Mexico, and southward comes to an end a few miles north of the city of El Paso.

The next range to the east, separated from the Franklin Mountains by the low-lying Hueco Bolson or Basin, enters

Texas from the north as the Hueco Mountains on the west and the Cornudas Mountains on the east. This range is essentially a broad plateau, the Diablo Plateau, surmounted by subsidiary mountains. One set of these is near the eastern and the other near the western border of the plateau. The western line of mountains begins on the north with the Hueco Mountains and Cerro Alto and continues southeastwardly in the Finlay, Sierra Blanca, Malone, Quitman, Devil's Ridge, and Eagle Mountains, which latter range is crossed by the Rio Grande in a canyon. The eastern line is made up successively from north to south by the Cornudas, Sierra Tinaja Pinta, Sierra Prieta or Black Mountain, Sierra Diablo, Baylor, Carrizo, Van Horn, Tierra Vieja, Chinati, Cienega, Sierra Bofecillos, and the Mesa de Anguila. Through the last the Rio Grande has cut the canyon of Santa Helena, 1,800 feet in depth and scarcely wide enough at the bottom to allow the passage of its turbid flood waters.

The easternmost range of Trans-Pecos Texas, forming in this latitude the Front Range of the Western Cordillera of North America, enters Texas on the north as the Guadalupe Mountains and is continued successively southward as the Delaware, the Davis (Limpia or Apache), the Mount Ord, the Santiago, and the Sierra del Carmen. The latter continues southward into Mexico, and is trenched by the deep and narrow canyons of the Rio Grande.

Minor mountains, east of the Front Range proper, are the Barilla, Sierra Madera, Glass (Vidrio, Comanche), the Marathon uplift, and a series of four long ridges cut through by the Rio Grande in deep canyons between the Sierra del Carmen and the mouth of San Francisco Creek. They are to be regarded as subsidiary arches and folds in Comanchean and earlier sedimentary rocks and in later lavas (in the Barilla Mountains). These folds gradually die out to the eastward as the intensity of the mountain-making forces diminishes in that direction.

The structure of the Trans-Pecos mountain region is broadly that of two anticlines or two great arches of sedimentary rocks, the eastern of which follows rather closely the crests of the Front Range while the summit of the western lies along the crest of the Franklin Mountains to the north of El Paso. The intermediate Diablo Plateau is of the nature of a broad downwarp, trough, or syncline, lying between the two great anticlines. The up-arching was greatest in amount at the north and there is a gradual southerly slope, both in structure and altitude, from the New Mexico line toward the Rio Grande. The major structure is complicated by numerous minor foldings and faults (breaks and dislocations) of the rocks, some of the latter of which are of great magnitude. The date of the last great mountain-forming movements, those which have formed the major features described above, is geologically rather recent. They occurred in the Pliocene or Pleistocene period. Older mountain-making movements are shown by structures in the older rocks, most noteworthy of which are the movements of the same date as those which formed the Ouachita Mountains of west-central Arkansas, and the Arbuckle and Wichita Mountains of southern and southeastern Oklahoma, as well as the old mountains of the central Texas mineral region. These old mountains, formed during the latter part of the Paleozoic era and buried beneath the sediments deposited by the seas of later times, are now uncovered by erosion of the later sediments in the vicinity of Marathon and in the Solitario, north of Terlingua. The rocks in these old folds were very closely pressed together so that layers of sandstone and limestone, which originally lay horizontal, now slant at high angles or even stand in vertical or overturned positions.

Another important epoch of mountain-making occurred in the Trans-Pecos region near the close of the Upper Cretaceous, and a fourth near the close of the Paleozoic.

There are large areas of igneous rocks which have broken through and now rest upon the sedimentaries. The igneous rocks are sparsely distributed in the region north of the line of the Texas and Pacific Railway. South of that railroad they cover large areas. They form intrusions which have broken through or bowed up the sedimentary rocks, and also great lava flows which have in many places buried the older rocks. Great plataeu areas of lava flows are found in the Davis Mountains, the country between Alpine and Marfa and west of the Mount Ord and Santiago Mountains and the Sierra del Carmen as far as to the Rio Grande and beyond into Mexico. Their greatest development coincides with the outlines of an area extending from the Davis Mountains south to the Rio Grande. This area, which includes the Chisos Mountains, represents a large block that has been relatively less elevated than any other part of the surrounding Cordilleran province. The relative sinking of this block in the general uplift has prevented erosion from yet removing all the igneous rocks covering the underlying sediments.

Broad flats or basins lie between the three major mountain ranges. They are for the most part filled by the debris derived from the wearing away by erosion of the mountains.

The western basin, between the Franklin Mountains and Diablo Plateau, extends from New Mexico southward to the Quitman and Eagle Mountains and beyond the Rio Grande. This is known as the Hueco Bolson or Basin. The eastern or Salt Basin lies between the Diablo Plateau and the Front Range and extends from New Mexico southeastward as far as the Chinati Mountains, where it ends. The Salt Basin has no outlet to the sea.

The country within the Great Bend of the Rio Grande, south of the Southern Pacific Railroad, bounded on the southwest by the Chinati Mountains, on the south by the Sierra Bofecillos, and the Mesa de Anguila, and on the northeast by the Mount Ord Range, the Santiago Range, and the Sierra del Carmen, is a great trough or syncline of Comanchean and Upper Cretaceous rocks partly covered by lava flows and intruded by igneous rocks. This is the lowest and broadest portion of the great syncline continued to the northwest in the Salt Basin.

An important minor anticline follows the southwest margin of the Diablo Plateau from New Mexico southward across the Rio Grande. The Hueco Bolson is structurally a downwarp or syncline, faulted down along the east base of the Franklin Mountains. North of the Texas and Pacific Railway the Salt Flat or Basin is also a downwarp, faulted down at both eastern and western margins; south of the Texas and Pacific, the faulting, though perhaps present, is not apparent, because of the covering of lava.

The physiography and structure of the Trans-Pecos mountains is very similar to that of other portions of the Colorado Plateau Province of New Mexico, Old Mexico, and Arizona and of the Great Basin province of Utah, Nevada, and southeastern California. This type of structure was named many years ago the Basin Range and Colorado Plateau structure, by Gilbert, Dutton, and Powell.

Many of the prominent peaks of the Trans-Pecos region are composed of igneous rocks. Such are Cerro Alto, the Cornudas, the Sierra Tinaja Pinta, Black Mountains or Sierra Prieta, Santiago Peak, Iron Mountain near Marathon, Sierra Blanca, the Chisos, Chinati, and Rosillos mountains, and others. Others, like Elephant Mountain and a number of the mountains of the Great Bend country, are remnants of a once more extensive lava plateau. Lava flows are responsible for broad flattish surfaces, like those of the Davis Mountains, the country between Alpine and Marfa, and southward to the Sierra Bofecillos, the Tierra Vieja Mountains, and others. The other prominences of the region are mainly formed by gently tilted broad mesas or ridges (cuestas) of resistant sedimentary limestones of Pennsylvanian, Permian, and Comanchean age. Such are the Sierra Diablo and the Sierra del Carmen, the Guadalupe, Delaware, Hueco, and Franklin mountains.

The Texas Plains

The plains of Texas are all much alike. For the most part they are nearly featureless, flattish, or gently undulating, broad expanses of country, which were in their primitive state either grass- or tree-covered. In the typical grassy plains, trees were confined to the stream valleys. In the forested regions there was either no break in the cover of timber or else glades or "prairies" interrupted the broad expanse of woodland. Different types of forest trees or scrub were characteristic of varying kinds of soils, and the soils are, in the regions away from the stream valleys, directly dependent on the nature of the underlying or bed rock.

When the rock layers have been disturbed from their original horizontal position they are said to dip and the amount of dip is their angle of deviation from the horizontal, while the direction of dip is that in which the down slope is the greatest. Almost all of the rock layers of the Texas plains have a slight dip. In the Trans-Pecos region this dip is easterly; in the plains of north-central Texas, it is westerly; and in other plains regions of the State it is southerly, easterly, or southeasterly. Whenever a firm bed of rock, more resistant to the forces of erosion than the adjacent layers, chances to outcrop, it will generally form a higher elevation than its surroundings. If the more resistant rock layer is horizontal or very nearly so, it will form a steep bluff along the edges of its outcrop, while its top surface will be markedly flattish. Such an elevation is called a *butte* or a *mesa*. If, however, the rock layer has a dip its upper surface will form a long flattish surface, gently sloping downward in the direction of the dip and on the opposite side there is usually a steep, abrupt bluff or escarpment. The escarpment faces in the direction opposite to that of the dip. The bluffs or escarpments and the long, gently sloping surfaces or *cuestas* together make up the more or less well-defined long and broad ridges which are a common and conspicuous feature of the Texas plains.

The Great Plains

The Texas plains may be subdivided into the Great Plains and the Gulf Coastal Plain. The boundary between these two runs from Red River in the vicinity of Denison, on the northeast, in a southwesterly direction to near San Antonio, and thence is continued in a westerly direction to Del Rio, where it crosses the Rio Grande. From the city of New Braunfels to the Rio Grande the Great Plains on the north are separated from the lower-lying Gulf Coastal Plain on the south by a distinct escarpment. This escarpment, known as the Balcones Escarpment, was formed differently from the escarpments discussed above. It was caused by a fault or dislocation in the rocks along which the rocks on the west and north sides have been lifted up relatively to those on the east and south sides. This same line or zone of faulting extends north-northeastward from Austin to the Red River and forms the boundary between the two plains. The amount of displacement is less north of New Braunfels than south and the break in the general eastwardly slope of the surface is not as marked as it is farther south.

The Balcones fault is the leading structural feature of Central Texas. The different rock formations for many miles on both sides of the fault trend in long belts parallel to the line of faulting, and dip in a direction at right angles to that line. North of Austin the fault runs in a direction slightly east of north; between Austin and San Antonio it gradually swings from a north-south to an east-west direction and continues in the latter direction from San Antonio to Del Rio.

The Great Plains lie east of the eastern base of the western Cordillera or mountain region and to the west and north of the Balcones escarpment. In Texas, the High Plains of the Panhandle, the Llano Estacado or Staked Plains, the Central Mineral Region, the north-central Texas Plains, the Edwards Plateau, the Grand Prairie, and the plains lying between the Pecos River and the mountains in Trans-Pecos Texas, belong to the Great Plains.

The Pecos Plains. The plains of the eastern Trans-Pecos region have a gentle easterly slope towards the Pecos River. The rocks of the region also dip eastward. At the southeast the rock is mainly Comanchean limestone; in the middle region, or the Toyah Basin, a more or less thick covering of Pleistocene and Recent gravels buries the underlying solid rock; at the north, Permian limestone, sandstone, shale and gypsum are exposed. The most prominent break in the gentle easterly slope is caused by the Rustler Hills, composed of Permian limestone and lying east of the Delaware and Guadalupe mountains.

The Edwards Plateau. The Comanchean limestones of the southeastern Trans-Pecos plains are trenched by the

Pecos River in a deep and narrow canyon, and are continued to the eastward as the Edwards Plateau, a surface formed on the Edwards and other limestones of Comanchean age. The Edwards Plateau reaches as far east as the Balcones Escarpment at Austin and to the Central Mineral Region of Llano, Burnet, Mason, San Saba, and Gillespie counties. The surface of the Edwards Plateau is in general quite flat with a very gentle southerly slope. Only two streams, the Colorado and the Pecos rivers, cut entirely across the Edwards Plateau and both these rivers were in existence before the time of the faulting which caused the Balcones Escarpment. This escarpment bounds the Edwards Plateau on the south. The northwest boundary of the Edwards Plateau is the Llano Estacado or Staked Plains, the northern boundary is the north-central Texas Plains and the northeastern boundary is the Colorado River.

The Central Mineral Region. The Central Mineral Region is a basin-shaped depression stripped by the erosion of the Colorado River and its tributaries of its former cover of Comanchean rocks. In the Central Mineral Region outcrop pre-Cambrian, Cambrian, Ordovician and Pennsylvanian (Upper Carboniferous) rocks. Although its surface is considerably rougher than that of the adjoining Edwards Plateau, it is, in reality, a low plains country. The lowest part of the Central Mineral Region is the area of outcrop of the pre-Cambrian rocks. Above the pre-Cambrian rocks the Cambrian, Ordovician, and Pennsylvanian rise in escarpments to broad flattish surfaces.

The Grand Prairie. North of the Colorado River the Edwards Plateau region loses some of its distinctive characteristics. The Edwards limestone, which formed its surface west of the Colorado, becomes much thinner and no longer forms its continuously flat surfaces. Also the Balcones Escarpment disappears as a conspicuous topographic feature in the region between Austin and Georgetown. The line of faulting, however, continues as a structural feature, and so it seems best to include the plain of Comanchean rocks between the Colorado and Red rivers as a portion of the Great Plains Province. Hill called this the Grand

Prairie, a name which is probably as appropriate as any. The Grand Prairie is bounded on the west by the north-central plains of Pennsylvanian and Permian rocks, and on the east by the Balcones Fault. It is entirely crossed by two rivers, the Red and the Brazos, and the headwaters of the Trinity reach back to within a few miles of its western margin. The Comanchean rocks of the Grand Prairie dip easterly.

The North-Central Plains. The North-Central Plains enter the State of Texas in the valley of the Red River and at the southeastern boundary of the Panhandle. They are bounded on the west by the high erosion escarpment of the Panhandle High Plains and the Llano Estacado; on the south by the northward-facing erosion escarpment of the Edwards Plateau and on the east and northeast by the westward and northwestward-facing erosion escarpment of the Grand Prairie. In the southern portion of the North-Central Plains a few island-like remnants of the formerly much more extensive Edwards Plateau rise in flat mesas and buttes above the general surface of the Eroded Plains. The rocks of the North-Central Plains are of Pennsylvanian and Permian age, and dip westward. They are sandstones, limestones, clays, shales, conglomerates, gypsum, and rock salt.

The Panhandle High Plains and the Llano Estacado. The Panhandle High Plains and the Llano Estacado constitute the southern portion of the High Plains proper, which extend from northwestern Kansas as far south as the Edwards Plateau and the valley of the Pecos River. The deep valley of the Canadian River separates the Panhandle High Plains from the Llano Estacado or Staked Plains. Both these divisions of the High Plains are similar in their characteristics. The High Plains region is a high isolated plateau or broad mesa, rising above surrounding rolling plains in a nearly flat, island-like mass. On the west, southwest, and south, the Llano Estacado is bounded by the valley of the Pecos, while its eastern escarpment is drained by the headwaters of the Red, Brazos, and Colorado rivers. The escarpment of the High Plains is formed by a limestone, locally known as the "cap rock." This is more resistant to forces of erosion than the underlying beds, and forms an abrupt, precipitous and nearly horizontal rim.

Excepting the Toyah Basin of the Trans-Pecos region and the coastal margin of the Gulf Coastal Plain, the High Plains differ from all the other plains of Texas in being a surface formed by deposition. The High Plains are practically destitute of trees and are characterized by a sparse, uniform covering of grasses. The surface has a general easterly to southeasterly slope of about nine and one-half feet per mile. The surficial rocks are later Cenozoic (Tertiary and Quaternary) in age and are for the most part unconsolidated. The deeper rocks consist of Permian and Triassic, and some small remnant of Comanchean rocks, the Comanchean being nearly altogether confined to the southern border where they merge into rocks of the same age in the Edwards Plateau. The structure of the Permian rocks is that of a very broad basin, downfold, or geosyncline, the lowest portion of which lies under the High Plains, and which embraces all the territory between the Western Cordillera and the Edwards Plateau and Grand Prairie.

The Gulf Coastal Plain

The Gulf Coastal Plain of Texas includes the eastern, southeastern, and southern portions of the State. The belt is narrowest between Austin and San Antonio and the coast of the Gulf. It is widest on the east, where it covers all the territory between Red River and the Gulf of Mexico, and along the Rio Grande, where it stretches from the mouth of the Devil's River to the Gulf. Its northern and western boundary is the Balcones fault. At the beginning of the Tertiary there existed two great embayments of the Gulf: one along the course of the Rio Grande, and the other in the lower Mississippi Basin, which extended as far north as southern Illinois. These embayments explain the widening of the belt of sediments making up the Gulf Coastal

Plain both to the east and west in Texas. From Austin northwards to the Red River the dip of the earliest formations in the Gulf Coastal Plain, of Upper Cretaceous age, is easterly. In all other portions of the Gulf Coastal Plain, sediments dip towards the present Gulf of Mexico; in northeast Texas southward, and in the south-central and southern portions, southeastward. The most abrupt change in dip comes in the region about Denison, east of which the beds dip southerly, and southeast of which they dip easterly. Where the change occurs there is the Preston anticline, a low fold with northwest-southeast axis, bounded on the west by a southeastward-plunging syncline. Another marked change in the direction of dip occurs in the southwest coastal plain in Maverick, Zavalla, Dimmit, LaSalle, and McMullen counties, where a southeastward-plunging syncline follows in general the course of the Nueces River. West of this syncline, in Maverick and Dimmit counties, are three very low southeastward-plunging anticlines.

The Gulf Coastal Plain has the lowest altitude of any portion of Texas. The surface slopes gradually towards the Gulf, but to a less degree than the dip of the strata, so that as the Gulf coast is approached, younger formations successively outcrop. The strip of country bordering the coast and extending for fifty to a hundred miles inland is very nearly flat, sloping towards the Gulf at the rate of about one foot to the mile.

The Gulf Coastal Plain is characterized by uplands of low relief and broad river valleys. The surface is more hilly and broken towards the interior or northwestern border, where it has been carved out of the older beds which have a higher altitude and have been for a longer time subject to erosion. Cuestas, or ridges, sloping gently to the southeast with a steep slope on the northwest, are formed in the eastern region by the outcrop of the Austin chalk, the Mount Selman iron ore member, and the Corrigan formations; and in the western region by the Austin chalk, Mount Selman, Fayette, Oakville, and Reynosa outcrops. The cuesta formed by the Reynosa is known as the Bordas.

Between the cuestas the less resistant formations outcrop with flattish or very gently rolling surfaces.

THE RIVERS OF TEXAS

The longest river having its course entirely confined to Texas is the Trinity. The headwaters of the Red, the Canadian, the Brazos, the Colorado, and the Pecos lie in New Mexico.

The Rio Grande

The Rio Grande, circling the entire southwestern border of the State, is the greatest river that touches Texas soils. It rises in south-central Colorado, crosses the entire State of New Mexico, and forms the border of Texas and Old Mexico for more than a thousand miles. It receives from Texas only two tributaries of any consequence—the Pecos and the Devil's rivers. It has a dry course at certain seasons between the New Mexico boundary and the mouth of the Rio Concho, which joins the main river at Presidio del Norte but the Concho affords a perennial water supply which is augmented farther downstream by supply from the Pecos, Devil's, Sabinas, and Salado rivers.

The Rio Grande is the oldest river of our region. It, or a predecessor occupying practically the same territory, was in existence in early Eocene time, for the early Tertiary sediments of the Rio Grande embayment were in large measure brought down by it. Even the upper portion of its course in Colorado came into existence by the end of the Eocene, if not earlier. Through this region the river meandered in flowing curves, indicating that it was then a river physiographically old. After this came a change. At a time which we cannot as yet definitely state, but either at the end of the Tertiary (late Pliocene) or early in the Quaternary (Pleistocene) the mountain ranges of West Texas were uplifted athwart its course. The river was able to cut down as fast as the mountains rose, and so today its course through the mountains is marked by a series of canyons. The Rio Grande canyons are not as deep as many other canyons in North America, but few of them are as narrow and tortuous in their courses as are canyons of the Rio Grande. From the point where the river enters the Eagle Mountains until it emerges on the east side of the Carmen Range, it alternately flows in mountain canyons and meanders through bolson plains. In the Trans-Pecos plains and in the southwestern portion of the Edwards Plateau the river runs in a practically continuous gorge in the Comanchean rocks.

Between El Paso and the Eagle Mountains, the Rio Grande flows in a broad valley through the depressed area of the Hueco Basin. From Del Rio to its mouth, the river also flows in a broad, in places terraced, valley similar to that of other rivers of the Gulf Coastal Plain.

The Pecos

The Pecos River in its course through Texas has a broad valley in the Toyah Basin, southwest of the Staked Plains. In this portion of its course the Pecos is relatively a young river, which has come into existence since early Pleistocene time. We know this to be the fact because the upper sediments of the Staked Plains are of late Tertiary and early Pleistocene age and were derived from the erosion of the mountains of the Cordillera. These sediments were deposited by streams flowing eastward from the mountains across the course of the present Pecos. There is evidence also that the portion of the Pecos River in southeastern New Mexico has captured for itself the former head waters of the Brazos River. In the region of the Staked Plains, its left tributaries are rapidly encroaching on the east divide and the river itself is gradually shifting its course down the dip of the rocks.

The lower course of the Pecos, or its gorge-like valley through the Edwards Plateau, was apparently in existence when the Balcones Escarpment was uplifted by faulting. The lower Pecos, like the Rio Grande and the Middle Colorado, was able to cut down as fast as the Edwards Plateau was uplifted, and hence maintained its course during and after this uplift.

The Canadian

The Canadian River in its course through the Panhandle is also probably as old as early Pleistocene at least, for it apparently deposited the early Pleistocene sediments rimming its valley and was able to maintain its course through the physiographic changes, probably brought about by uplift, which have formed the Llano Estacado and the Panhandle High Plains into a high isolated plateau bounded nearly everywhere by steep escarpments of erosion.

The Canadian has a relatively narrow valley in its course across the Texas Panhandle. The distance between the heads of the short tributary creeks on opposite sides of the stream in the Panhandle Plain average not more than thirty-five miles. It is a wide sand-choked stream for practically its entire course across the Panhandle. The stream has continuously flowing water for only a portion of the year and is noted for its sudden rises and treacherous quicksands. Across the Panhandle the stream has cut a broad canyon in the High Plains. Locally the high bluffs approach nearly to the river, but generally the sandy flat flood plain is from two to four miles wide. The channel of the river is a sand-bed, averaging about three-fourths of a mile in width. In places, where the river flows between high bluffs, the stream is not more than 200 yards wide. Today, in its course across the Panhandle, it is at grade and it has built up a flood-plain which is generally broad and deeply filled with alluvium.

The Red, the Brazos, and the Colorado

The Red, Brazos, and Colorado rivers have their head courses in the Llano Estacado of New Mexico, but become permanent streams only when fed by springs near the eastern escarpment of the Llano. All these streams may once have headed in the eastern flanks of the New Mexico mountains, but only of the Brazos is this supposition as yet fairly certain. These streams, in their courses across the Llano Estacado, have very shallow and relatively narrow courses, their gradients in some places being actually less than the general eastwardly and southeastwardly slope of the plains surface. Near the eastern escarpment of the Llano Estacado these valleys have narrow and deep canyons, with the more resistant rock layers forming terraces in the canyon walls and falls where they are crossed by the stream channels. The two most noteworthy of the canyons are the Palo Duro and the Tule, which in their deepest portions are seven to eight hundred feet in depth and exhibit the most characteristic "bad lands" scenery to be found in Texas. Upon leaving the region of the high escarpment the valleys become much broader and are sand-choked, with low bounding bluffs. In dry seasons, all these streams cease flowing for certain portions of their courses, although water seeps through the river sands. Through the entire distance from the Staked Plains escarpment to the Gulf, these three rivers meander broadly in their courses and the valley bottoms gradually become wider and wider as they near the Gulf.

The Colorado River has a meandering gorge between Marble Falls and Austin, caused by the persistence of the meanders of an already old river across the Edwards Plateau at the time of the uplift caused by the Balcones faulting. The history of the river in this portion of its course is similar to that of the lower Pecos and the Rio Grande between Presidio del Norte and the mouth of the Devil's River.

The Rivers of the Gulf Coastal Plain Proper

The older rivers of the Gulf Coastal Plain include the Sabine, Neches, Angelina, Trinity, the lower courses of the Red, Brazos, and the Colorado, the Guadalupe, the San Antonio, and the Nueces. All except the Sabine, Neches, San Antonio, and Angelina have extended their headwaters back into the Great Plains. All these rivers have a general southeasterly course in accordance with the general slope of the surface, and all have broad valleys with wide bottoms, low bounding bluffs, and meandering courses. All have undergone a similar history and all have valleys of later age than the Lafayette-Uvalde formation of late Pliocene or early Pleistocene age.

The main rivers have extended courses across the Coastal Belt of country extending from fifty to one hundred miles inland from the shores of the Gulf. The valleys are here shallow gorges or trenches with steep but low valley walls. The valleys of the shorter streams, good examples of which are the San Jacinto River and Buffalo Bayou near Houston, have V-shaped trough valleys in the flat upland surface and are generally characterized by few tributaries.

THE LAKES OF TEXAS

Lakes are few and relatively unimportant in Texas. No portion of the State was glaciated in the Pleistocene and consequently the glacial lakes which occur in most other parts of the United States are entirely lacking. Similarly there has been no recent volcanic activity which would cause lake basins by the formation of lava dams. There is only one enclosed basin in Texas which has been formed by tectonic or deformative action. This is the Salt Basin of the Trans-Pecos region, the lowest part of which is the site of a playa or salt lake which is dry except for short periods after heavy rainfalls.

All the other lakes of Texas have originated in one of three ways. The lakes of the plains of the North-Central region, and of the High Plains of the Llano Estacado and Panhandle regions occupy areas of ground settlement (sink holes) formed by the solution of underlying beds of salt, gypsum or limestone. In the flood plains or first bottoms of the principal streams of the Gulf Coastal Plain bayou lakes occupying the sites of former channels of the stream are often found. Sometimes the main stream itself is partially dammed by the formation of a tangled mass of logs and other vegetation upon which trees and other plants grow. Such masses form floating dams which impound the waters of the stream and form a more or less permanent lake.

The Coast-Line of the Gulf of Mexico

The coast-line of Texas is remarkably even and low. Sand bars and spits are greatly developed. There is nowhere close to shore sufficiently deep water to afford a good natural harbor. The bays or estuaries at the mouths of all the Coastal Plain rivers except the Brazos and the Rio Grande appear to indicate that there has been a rather recent submergence of the coast-line, which has not been great in amount. It may possibly be that the Brazos and Rio Grande have carried more sediment into the Gulf than other Texas rivers, and so have been able to fill up the estuaries as soon as they were formed. If not, it would be necessary to hold that the submergence affecting other portions of the Texas coast did not affect the regions of the mouths of the Brazos and Rio Grande. A recently uplifted beach line, about thirty feet above present Gulf level, is found at Corpus Christi.

The shore drift moves in a southwesterly direction, being deposited by the waves generated by prevailing southeasterly winds. The delta of the Mississippi contributes most of the sediments as far west as Galveston. East of this point the line marking a depth of ten fathoms in the Gulf waters is more than twice as far from shore as it is west of Galveston. To the west, the water close in shore becomes very gradually deeper, the ten fathom line being closer to shore at the mouth of the Rio Grande than anywhere else on the Texas coast.

The most remarkable sandbar of all is Padre Island, which stretches from Corpus Christi to Point Isabel. Between these two points no stream of any importance enters the Gulf. Padre Island is apparently a barrier ridge, formed along the line of breakers of the incoming waves. Storm waves have built up the sand above the surface of the water, and so have shut in the Laguna Madre behind.

The Laguna Madre is being filled with sediment washed down from the mainland.

Deltas at the mouths of Texas rivers are confined to such rivers as enter lagoons and estuaries, which they will gradually fill up with deposits unless the sinking of the coastal border is at least as fast as the rate of deposition. Sediments brought to the Gulf by the Brazos and the Rio Grande appear to be removed at an equal rate by shore drift by the waves; and so no deltas are being formed at the mouths of the only two streams which empty directly into the Gulf.

The dominant process now operating along the Texas coast is deposition. This has resulted in the formation of a remarkably even coast-line with everywhere shallow water near the shore. It is evident that during the Tertiary the dominant process was always or almost always deposition. Today, as in the Tertiary times of the past, the land area is gradually growing at the expense of the Gulf.

CHAPTER II

GEOLOGY

BY J. A. UDDEN, C. L. BAKER AND EMIL BÖSE

GENERAL STATEMENT

Materials that form the outer surface of the earth in considerable quantity are called rocks. They may be soft or hard, and they are either sedimentary rocks or igneous rocks, according to the conditions under which they were formed.

Sedimentary or Bedded Rocks

The sedimentary rocks have been produced by deposition of the waste of the land mostly in seas and lakes and in river valleys. Deposits made by glaciers and those consisting of dust and sand blown by the atmosphere, are also included in this class of rocks. Sediments have mostly formed in bedded layers, or in strata, and sedimentary rocks are therefore also known as bedded or stratified rocks. They include soft or hard accumulations of calcareous slime, mud, clay, sand and gravel. There are also chemical precipitates such as salt and gypsum. It is estimated that sedimentary rocks cover about 97.6 per cent. of the surface of the State of Texas. They underlie most of this area to depths of several thousand feet.

Igneous Rocks

The igneous rocks consist of materials which have been forced up to the surface, or to near the surface, while in a molten, liquid or semi-liquid condition. The molten liquids have afterward congealed into crystalline or glassy masses. Among these rocks we have lava, basalt, diorite, andesite, rhyolite and some kinds of granite. Igneous molten material has been forced up in regions where the earth's exterior has been at some time disturbed, mostly in mountainous districts. Such material is also sometimes found in other districts where the ground has been affected by fractures and by folding. In Texas igneous rocks occur in the mountainous section west of the Pecos; in the so-called Central Mineral Region, comprising Llano and Mason counties, and parts of adjacent counties; and along the outer border of the Central Great Plains. This border is known as the Balcones Escarpment, and it is a belt in which the ground has been broken and flexed, as the Gulf Coastal Plain settled to a lower level on the east. Igneous rocks occur at several points in this belt, especially in Williamson, Travis, Uvalde, and Kinney counties, covering perhaps less than a score square miles. Except in the localities enumerated, igneous rocks are unknown in Texas. It is estimated that igneous rocks probably cover no more than 6,500 square miles of the surface of the State. This is only about two and four-tenths per cent of its area.

Past Geographical Changes

Since the time the earliest sedimentary rocks were laid down within the boundaries of Texas, this part of North America has been several times submerged under the sea, wholly or in part, and it has as many times been again partly or wholly elevated to make a part of the mainland of the changing continent. During most of these submergences, sediments were deposited that measure thousands of feet in thickness. These beds were in turn again eroded and in part removed from the land during each subsequent emergence. The result is that we now find most of the land in Texas made up of limestone, clay, shale, and sandstone, extending to depths of thousands of feet. None of any group of these rocks made in the same sea extends over the entire State. The later deposits always overlie the earlier.

Fossil Remains

In each of the groups of sediments remains of animals and plants were imbedded and may yet be found as fossils. These are different for the various groups of rocks. By observing the fossils in each of the strata, and by following the formations from place to place across the State, and noting their character and their succession, geologists have already learned much of the general facts as to thickness and relative age of the bedded rocks over most of the State. A summary of this information is presented in the following pages, and in the accompanying map and sections. The following table gives the names and indicates the age of the larger divisions of sedimentary rocks known in the State. These will here be briefly described in the order from the earliest to the latest. A separate chapter is written on the igneous rocks.

Synoptic Table of Sedimentary Rocks Known in Texas

Cenozoic	Quaternary	Recent
		Pleistocene
	Tertiary	Pliocene
		Miocene
		Oligocene (?)
		Eocene
Mesozoic	Cretaceous	Upper Cretaceous
		Comanchean
	Jurassic	
	Triassic	
Paleozoic	Anthracolitic	Permian
		Pennsylvanian
		Mississippian (?)
	Devonian (?)	
	Silurian	
	Ordovician	
	Cambrian	
Archeozoic:	Pre-Cambrian	

SEDIMENTARY ROCKS

The largest general divisions into which the sedimentary rocks are classified are, like the smaller divisions, based largely on the nature of fossil animals and plants which they contain. These are four: Archeozoic (first life); Paleozoic (ancient life); Mesozoic (middle life); and Cenozoic (recent life).

ARCHEOZOIC

PRE-CAMBRIAN

The pre-Cambrian rocks are in this State largely covered by the deposits of later ages. They have for the most part been greatly changed by heat and pressure, so as to possess generally a crystalline texture. Fossils which they no doubt once contained, have been completely destroyed or obliterated, so as to be entirely unrecognizable. In most parts of the world these rocks have also been greatly folded and faulted. The once horizontal layers now mostly stand at high angles. In Texas these rocks are exposed in the Central Mineral Region and at a few points in the mountains west of the Pecos. Over the greater part of the State they underlie the other formations at depths varying from a few hundred feet to probably more than 10,000 feet below the surface. The most important formations of this era which have been described are five.

ARCHEOZOIC ROCKS IN TEXAS

Central Mineral Region	Van Horn Region	El Paso Region
Valley Spring gneiss Packsaddle schist	Millican Carrizo	Lanoria quartzite

CENTRAL MINERAL REGION

Packsaddle Schist, and Valley Spring Gneiss

These two formations consist of schists and gneisses and are mostly dark crystalline rocks, containing quartz, feldspar, amphibole, mica, biotite, graphite, tourmaline and other minerals. They contain bands of quartzite, limestone and graphitic schist, which prove their sedimentary origin. In addition they contain sheets of intruded igneous rocks. These also have been altered. They have been invaded by large intrusions of granite, and of darker igneous basic rocks, such as gabbro and diabase. These intrusives are probably also of pre-Cambrian age and they underlie a large part of the area mapped as pre-Cambrian in the

Central Mineral Region. All these rocks are complexly folded and faulted. The discernible strata usually stand edgewise at high angles, and have a general trend from northwest to southeast.

These rocks contain mineral deposits of various kinds, which may be developed and prove useful. The limestone layers have been changed to marble. Granite suitable for building stone exists in enormous quantities. This rock has been extensively quarried. Iron ore occurs in these rocks apparently as stratified bodies of magnetite, a few of which are probably large enough to be profitably worked under favorable commercial conditions. Graphite likewise occurs in layers and seams that clearly represent originally stratified deposits. These layers occur interbedded with marble in the Packsaddle schists in many places. There are also considerable deposits of serpentine and talc, which are the result of processes that have profoundly changed the nature of the ancient rocks in this region. Deposits of galena, fluorite, zinc blende, arsenical iron pyrite, minerals of copper, manganese ore, and gold-bearing quartz are known to exist in several places. Barringer Hill, in Llano County, is noted for the occurrence of rare-earth minerals, such as fergusonite, gadolinite, and cyrtolite, in such quantities as to be of value.

The Van Horn Region

The *Carrizo formation* consists of some strongly folded schist and gneiss exposed in the Carrizo Mountains, south of the Diablo Mountains and west of the Wylie Mountains.

The *Millican formation* consists of dark red, silty sandstone; dolomitic, semi-crystalline limestone, containing layers of chert; and conglomerate. It occurs in the country immediately south of the Diablo Mountains. This formation may be Cambrian. The Hazel silver mine near Van Horn is on a fissure vein in this formation.

The El Paso Region

The *Lanoria Quartzite* is described as having variable bedding and as changing from white to gray. Its thickness is estimated at 1,800 feet. This quartzite may be Cambrian in age.

In the Quitman and the Van Horn mountains, pre-Cambrian rocks are also believed to be found, but these have not yet been described.

PALEOZOIC

All of the five Paleozoic systems are represented in Texas: the Cambrian, the Ordovician, the Silurian, the Devonian, and the Anthracolitic. Rocks of the Devonian system have not yet been definitely proven to exist in the State, but they are probably present.

CAMBRIAN

Central Mineral Region	Marathon Region	Van Horn Region	El Paso Region
Ellenburger limestone (in part) Wilberns Cap Mountain Hickory sandstone	Brewster formation	Van Horn sandstone	Bliss sandstone

CENTRAL MINERAL REGION

In the Central Mineral Region deposits of the Upper Cambrian age have a combined maximum thickness of about 1,350 feet. These rocks overlie the granites, schists, and gneisses of pre-Cambrian age, in a belt which encircles this uplifted region almost continuously. This belt is from five to fifteen miles in width. The rocks dip away from the Llano uplift in all directions, and they are cut by many faults which tend to radiate from the center of the uplift. In parts of Gillespie County this belt of outcrop is covered by the Comanchean limestones, and in the vicinity of Marble Falls it is interrupted by a sunken block where it is covered by Pennsylvanian or Mississippian shale and limestone.

The Cambrian rocks have been described as making four formations, which apparently have been deposited in the same sea, and lie in conformable succession. Named in order from below upward, these formations are the Hickory sandstone, the Cap Mountain formation, the Wilberns formation, and the lower and main part of the Ellenburger limestone.

The Hickory Sandstone

This formation directly overlies the Packsaddle schist, the Valley Spring gneiss, and their intrusives in the Central Mineral Region. It varies from a few feet to 350 feet in thickness. It has a basal conglomerate which is variable in thickness as well as in composition. It frequently contains boulders and pebbles from the underlying pre-Cambrian rocks and from their intrusives. The formation is described by Paige as grading upward into the Cap Mountain limestone, from which it is not separated by any trenchantly marked limit.

The Cap Mountain Formation

This formation has a thickness of about 90 feet. It overlies conformably the Hickory sandstone in the Llano country, and consists of limestone and sandstone, both more or less glauconitic. The green grains of glauconite are specially abundant in cross-bedded sandstones which constitute the top of the formation.

The Wilberns Formation

This formation consists in its lower two-thirds mainly of thin-bedded, in many places sandy, limestones. The upper third of the formation consists of shale, with some limestone uppermost, and with interbedded small conglomeratic layers. The greatest thickness of the Wilberns formation is given as 220 feet.

The Ellenburger Limestone

The Ellenburger limestone is a formation which is believed to be in part of Cambrian age and in part Ordovician.

It overlies the Wilberns formation in the Llano country, and is probably 1,000 feet thick. It is a crystalline dolomite, of somewhat variable texture, and contains much white and yellow chert. The bedding planes are generally not well marked. The upper one or two hundred feet of the formation is more calcareous than the lower main part. Oolitic layers are present and there are calcareous conglomerates in both the lower and upper layers. It is not yet known if there is an unconformity between the Wilberns formation and the basal part of the Ellenburger limestone. There is strong evidence that the upper part of this limestone is Ordovician in age, while the lower part is Cambrian. It has even been suggested that these two parts are separated by an erosional unconformity.

MARATHON REGION

The Brewster Formation

Some small areas underlain by rock of upper Cambrian age have recently been discovered by Baker in the ancient eroded mountain folds in Brewster County, from five to thirty miles south of Marathon. The name of Brewster has been given to these beds. They consist of interbedded dark-colored sandstones and shales, the total thickness of which is unknown.

VAN HORN REGION

The Van Horn Sandstone

This formation has been described by G. B. Richardson, who found it to have a maximum thickness of nearly 700 feet. It occurs in some limited areas in the valleys between the mountains from three to thirteen miles northwest of Van Horn. Its lower part is a coarse-grained red and soft sandstone, containing some beds of conglomerate. The upper part of the formation is of somewhat finer grain, in places gray, and containing some quartz gravel. No characteristic fossils have yet been found in this rock, but, like some red Cambrian sandstone elsewhere, it has numerous structures resembling worm borings. On account of its relation to other formations it is believed to be Upper Cambrian in age.

EL PASO REGION

The Bliss Sandstone

Richardson describes this formation as a massive, fine-textured, brownish, indurated sandstone with a maximum thickness of 300 feet. It occurs in the eastern base of the Franklin Mountains north of El Paso, and is found also in a few places in the Hueco Mountains. North of El Paso the basal part of the formation is hard enough to be called quartzite. Higher up in the Hueco Mountains it is less indurated. Conglomerates occur in the basal part of the sandstone. Annelid borings, such as were noted in the Van Horn sandstone, are abundant also in this rock, and it contains fossils from which its Cambrian age is determined beyond doubt.

ORDOVICIAN

When not removed by recent erosion, rocks of Ordovician age overlie the Cambrian in all places where the latter system has been found in this State.

Central Mineral Region	Van Horn and El Paso Regions	Marathon Region
	Montoya limestone	Maravillas chert Marathon Series
Ellenburger limestone (in part)	El Paso limestone	

CENTRAL MINERAL REGION

Ellenburger Limestone

In the Central Mineral Region the upper part of the Ellenburger limestone is known to be of Ordovician age. although the exact limit between the Ordovician and the

Cambrian divisions in this limestone has not yet been determined. In its uppermost two hundred feet this limestone is somewhat less dolomitic than in the lower three-fourths of the formation. The bedding planes are also somewhat more distinctly marked in the more calcareous beds. The distribution of this limestone has already been described in connection with the rocks of the Cambrian system in the Central Mineral Region. It forms a broken ring-like area surrounding the pre-Cambrian formations.

VAN HORN AND EL PASO REGIONS

El Paso Limestone

This formation is a dolomite or dolomitic limestone about 1,000 feet thick, forming the greater part of Beach Mountain a few miles north of Van Horn. It outcrops in a broken belt on the east flank of the Franklin Mountains north of El Paso. It also occurs in an elongated area extending from northwest to southeast on the southwest edge of the Hueco Mountains.

Montoya Limestone

This formation, which formerly had been included in the El Paso limestone, was separated from it by G. B. Richardson in 1909. It has a thickness of about 250 feet. It is a dark to light gray, massive to thin-bedded, dolomitic limestone, including locally a bed of sandstone at the base, and thin bands of black and white chert in the middle. The Montoya limestone represents part of the upper Ordovician. It is found near El Paso in the Hueco and Franklin mountains; near Van Horn on the northeastern portion of Beach Mountain; and at the south end of Baylor Mountains.

MARATHON REGION

Marathon Series

Overlying the upper Cambrian Brewster formation is a group of rocks, named by Baker the Marathon series.

The Marathon series comprises, so far as yet known, the following succession of strata beginning at the base:

1. Interbedded dark-colored sandstones and shales, at least 300 feet thick, carrying Lower Ordovician fossils at a horizon 100 feet below the top.
2. Fine-grained, coarse-grained and conglomeratic sandstones interbedded with green or light bluish-gray shales at least 300 feet thick, the precise age of which is unknown.
3. Dark gray thin-bedded limestone. 130 feet thick, of Lower Ordovician age.
4. Interbedded green, gray and black shales and thin brown sandstones, about 500 feet thick, the exact age of which is unknown.
5. Yellowish-brown shales interbedded with thin gray limestones, about 375 feet thick, of Middle Ordovician age.

This entire succession has not yet been found at any one locality and it may contain other members not yet known. In places one or more of the upper members were removed by erosion prior to the time of Maravillas chert deposition.

Maravillas Chert

A younger formation has been named by Baker the Maravillas chert. There is in most, if not all, places an unconformity separating the Maravillas chert from the underlying and older Marathon series. The lower part of the Maravillas chert is of Middle Ordovician age, consisting of hard gray limestone with nodules and lenticular masses of dark-colored chert. The greatest known thickness of the Middle Ordovician portion of the Maravillas chert is about 400 feet, but often only a few feet are found.

The upper 300 feet of the Maravillas chert is of Upper Ordovician age. It consists of thin alternating beds of dark-colored chert and gray limestones, often conglomeratic.

SILURIAN

Very few places are known in Texas where the Silurian occurs. As far as our present knowledge goes, it is entirely lacking in Central Texas, and in the western part of the State it occupies a very limited area.

Fusselman Limestone

The name of this formation was proposed by G. B. Richardson in 1909 for a massive, dolomitic limestone, which is mostly white, or light-gray, but which also has some darker rock. Its thickness is estimated at about 1,000 feet. The Fusselman limestone occurs principally in the northern part of the Franklin Mountains, immediately south of the State boundary, and also in the middle part of this range, and in some isolated hills north of El Paso. Farther east it is found on the Hueco Mountains. This limestone represents the middle Silurian or Niagaran.

DEVONIAN

Caballos Novaculite

The Caballos novaculite overlies unconformably the Maravillas chert in the Marathon Basin. It consists of brown, cream-colored and white novaculite interbedded with green and vari-colored cherts. The greatest thickness known is 630 feet but owing to subsequent erosion, locally a much less thickness is found. No fossils have been found in the Caballos novaculite but E. O. Ulrich regards its age as Oriskany, the upper part of the Lower Devonian.

The Pre-Carboniferous Unconformity

Except possibly in the Marathon region, up to the present time, no Devonian has been discovered in Texas. In all other places where the earlier and later Paleozoic beds have been found in continuous cross-sections, the Anthracolitic beds rest unconformably either on the Ordovician or on the Silurian.

We do not know what kind of earth movements have taken place during this epoch. It is possible that there has

TABLE SHOWING THE CLASSIFICATION OF THE CRETACEOUS FORMATIONS

	Formation names (Synonyms in parenthesis)	East and Central Texas: Rio Grande	Uvalde	Austin	Waco	Fort Worth	Red River region	Trans-Pecos region: Quitman Mts. country	Big Bend country
Upper Cretaceous	Navarro beds (Eagle Pass formation, Webberville formation, Glauconitic division, Upper Arenaceous series, Bexar formation)	Escondido beds Coal Series San Miguel beds	Pulliam formation Anacacho formation	Webberville beds	Navarro beds	Navarro beds	Kemp clays Corsicana beds Arkadelphia clay	Vieja series San Carlos beds	Chisos beds Tornillo clay Rattlesnake beds
	Taylor marls (Exogyra ponderosa marls)	Upson clay	Taylor marls	Taylor marls	Taylor marls	Taylor marls	Taylor marls Marlbrook marls		Terlingua beds
	Austin chalk	Austin chalk (Pinto limestone)	Austin chalk	Austin chalk	Austin chalk	Austin chalk	Anona chalk Brownstown marl	Austin chalk	
	Eagle Ford shales	Eagle Ford shales (Val Verde flags)	Eagle Ford shales	Eagle Ford shales	Eagle Ford shales	Eagle Ford shales Woodbine formation: Lewisville beds	Eagle Ford shales Woodbine formation: Lewisville beds	Eagle Ford shales	Boquillas flags
Comanchean Cretaceous	Buda limestone (Shoal Creek limestone, Vola limestone)	Buda limestone	Buda limestone	Buda limestone	?	Woodbine formation: Dexter beds	Woodbine formation: Dexter beds	Buda limestone	Buda limestone
	Del Rio clay (Arietina clay)	Del Rio clay	Del Rio clay	Del Rio clay	Del Rio clay	Pottsboro group: Grayson marls, Mainstreet beds	Pottsboro group: Grayson marls, Mainstreet beds	Del Rio clay	Del Rio clay
	Georgetown formation	Devils River limestone	Georgetown formation	Georgetown formation	Georgetown formation	Weno group: Paw Paw beds, Quarry limestone, Weno formation Denton group Fort Worth limestone Preston beds: Duck Creek beds, Kiamitia clays	Weno group: Paw Paw beds, Quarry limestone, Weno formation Denton group Fort Worth limestone Preston beds: Duck Creek beds, Kiamitia clays	Georgetown formation	Edwards limestone
	Edwards limestone (Caprina limestone, Barton creek limestone)		Edwards limestone	Edwards limestone	Edwards limestone	Goodland limestone	Goodland limestone	Finlay formation	
	Comanche Peak limestone		Comanche Peak limestone	Comanche Peak limestone	Comanche Peak limestone			Cox formation	
	Walnut clays (Texana beds, Exogyra Texana beds)			Walnut clays	Walnut clays	Walnut clays	Walnut clays	Campagrande formation	Shafter beds
	Paluxy formation		Glenrose formation	Glenrose formation	Paluxy sands	Paluxy sands	Antlers sands	Bluff bed	
	Glenrose formation (alternating beds)				Glenrose formation	Glenrose formation		Quitman bed	Presidio beds
	Travis Peak formation			Travis Peak formation	Basement sands	Basement sands		Mountain bed	
	Lowest Comanchean							Lowest Comanchean	

been an uplift at the end of the Ordovician and the Silurian and that our country was above the sea all the time during the Devonian age and part of the Carboniferous. This uplift probably has not taken place at the same time in the whole State. In the central part of Texas we find the Carboniferous resting on the Lower Ordovician. The Silurian and Devonian may never have been deposited there. The country may have risen above the sea-level at the end of the Lower Ordovician and remained dry land until the end of the Lower Carboniferous period. It is impossible to ascertain the exact conditions because the older Paleozoic rocks in Central Texas are exposed only for a very short distance in Llano, Burnet, Gillespie, Blanco, Lampasas, San Saba, McCulloch, Mason, and other counties. In all the rest of east and central Texas the Paleozoic rocks are covered by the Cretaceous and the Tertiary. There are a few deep wells which extend below the base of the Cretaceous. One which was made at Georgetown shows below the Cretaceous a black indurated shale that probably belongs to the pre-Paleozoic. The Anthracolitic seems to be missing in that locality. Similar sheared and fissured slaty shales have recently been found under the Comanchean Cretaceous in two other borings, at Leon Springs in Bexar County and near Maxwell in Caldwell County. All of these occurrences make it probable that the Anthracolitic is absent or much folded along the Balcones escarpment.

In the western part of Texas we find the upper Anthracolitic lying on different strata of the older Paleozoic. In the El Paso region we find it on the Silurian (Fusselman limestone); farther to the east, near Van Horn, we find it covering the Upper Ordovician. In the Marathon region we find the Anthracolitic lying on a series of chert beds.

With the few data at hand we are not able to conclude whether the Silurian, Devonian, and lowest Anthracolitic have never been deposited, or whether they have been removed by erosion.

Everywhere in central, as well as in west Texas, we find the Anthracolitic lying on the older Paleozoic without any apparent angular unconformity. In the Van Horn region, however, the older Paleozoic rocks show a very slight tilting. In the Marathon region the lower Paleozoic is intensely folded, but this movement has taken place much later, during the Pennsylvanian period, and the earliest Anthracolitic rocks lie on the older Paleozoic rocks without showing any angular unconformity.

ANTHRACOLITIC

(Carboniferous in wider sense)

This system is one of the most important, on account of its wide distribution and its economic value. The Anthracolitic is divided in America into three principal series: the Permian (upper), the Pennsylvanian (middle), and the Mississippian (lower). Of these only the Pennsylvanian and the Permian have been known to exist in Texas.

	Central and North Texas		Southern Trans-Pecos	Northern Trans-Pecos
Permian	Double Mountain		Gilliam	Red Beds
	Clear Fork		Vidrio	Rustler
	Wichita		Word	Castile
	Albany		Leonard, Hess, Wolfcamp	Capitan limestone
			Ciboio	Delaware Mountain
Pennsylvanian	Cisco		Gaptank, Alta, Cieneguita	Hueco limestone
	Canyon			
	Strawn			
	Bend series	Smithwick shale	Haymond	
		Marble Falls limestone	Dimple	
		Lower Bend shale	Tesnus	
Mississippian (?)			Caballos novaculite	

MISSISSIPPIAN (?)

The Bend series of the Central Mineral Region was thought by J. P. Smith to be Upper Mississippian (St. Louis-Chester), but will here be described under the heading of the Pennsylvanian.

A limestone some 400 feet thick, has recently been reported by Dr. J. W. Beede as Mississippian, from the west side of the Hueco Mountains in El Paso County. It contains such fossils as Pentremites and Archimedes.

PENNSYLVANIAN

The Pennsylvanian has been found in central, north, and west Texas. The character of the rocks that compose the Pennsylvanian not being the same in all three regions, different subdivisions have been made in each of them. We shall describe them here in a geographical order.

Central and North Texas

The Pennsylvanian of central and north Texas has been subdivided first by W. F. Cummins in his "Report on the Geology of Northwestern Texas." The names given by him to the several subdivisions are, from below to above: the Bend, Strawn, Canyon, Cisco, and Albany formations. Originally, Cummins distinguished in north Texas another, the Millsap formation, between the Bend and the Strawn formation, but he conceded in 1912 that this name should be abandoned, because the Millsap must be considered as only a part of the Strawn formation.

Bend Series

This series consists principally of an upper and a lower bed of dark, soft shales, separated by a white, or dark and light gray, or bluish to black limestone, many beds of which contain nodules of chert. The entire thickness of the series exceeds, in some parts, 1,000 feet; in others it is less, but the lower shales seem to be missing there. The Bend formation is exposed only in narrow belts on different sides of the mass of older Paleozoic rocks (Cambrian and Ordovician) in the Central Mineral Region. Sidney Paige, in the Llano-Burnet folio of the Geologic Atlas of the United States, Washington, 1912, has shown that in this region the Bend formation is composed of two principal subdivisions, the *Marble Falls limestone* below, and the *Smithwick shale*, above. The age of the Bend is probably early Pennsylvanian.

Lower Bend Shale. The Lower Bend Shale is a formation noted by Udden, immediately overlying the Ordovician in the region south and east of San Saba, in San Saba County. It is a black fissile shale of uniform texture, evenly bedded, and highly bituminous. It contains some layers of dark limestone, and measures about fifty feet in thickness.

Marble Falls Limestone. At the bottom is always found a thin limestone conglomerate or breccia; the rest is composed of "alternating beds of dark and light gray, dove-colored, and dark blue to black, limestone." "Many beds contain abundant cherty nodules, largely of dark or black color." Its thickness is not more than four hundred and fifty feet. It is principally distributed in the southeast corner of the Burnet quadrangle and northeast of Bluffton and in the Riley Mountains. The same limestone is found also elsewhere, as for example, in several places on the upper San Saba River, on the Colorado River, southeast of San Saba, in a creek some miles west of Lampasas. and on the Pedernales River.

Smithwick Shale. Soft, dark to black, carbonaceous shale, with sandstone lentils composes this division. It lies on the Marble Falls limestone and has nearly the same distribution. Its thickness does not much exceed four hundred feet.

Strawn Formation

The Strawn formation consists principally of sharp-grained, moderately hard, evenly-textured sandstones, alternating with beds of blue clays. Conglomerates and shales are found in several parts of the formation; limestones are rare. In the northern region (Millsap, Parker County) the lower exposed part is composed principally of blue and black clays, little sandstone, and occasional thin beds of hard limestone and sandy shale. In the same region the upper part of the Strawn formation consists mainly of sandstones alternating with beds of blue clay, some conglomerate and shales; while limestones are rare.

The whole thickness of the formation, which can be measured only in central Texas, is more than four thousand feet.

The Strawn formation is exposed in central Texas, principally in Mills and San Saba counties, in a triangle between Brownwood, Brown County, Nix, Lampasas County, and Lookout Mountain, San Saba County. It lies unconformably on the Bend.

In north Texas this formation contains several coal seams.

In his valuable Report of the Colorado Coal Field of Texas, published in the Fourth Annual Report of the Geological Survey of Texas, N. F. Drake named, mapped and described no less than sixty-six different units in the section of the Pennsylvanian and the Permian along the Colorado River. These it has been impossible to describe or map in the present review, and only their names can here be given for reference.

The Strawn thus contains, in the order from below upward, and with Drake's numbers: (4) Lynch Creek bed; (5) Burnt Branch bed; (6) Elliott Creek bed; (7) Shadrick Mill bed; (8) Bed Number 8; (9) Fox Ford bed; (10) Horse Creek bed; (11) Bull Creek bed; (12) Big Valley bed; (13) Brown Creek bed; (14) Spring Creek bed; (15) Cottonwood Creek bed; (16) Hannah Valley bed; (17) Rough Creek bed; (18) Buffalo Creek bed; (19) Wilbarger Creek bed; (20) Comanche Creek bed; (21) Indian Creek bed; (22) Antelope Creek bed; (23) Ricker bed.

The Canyon Formation

This formation is composed of alternating beds of rather rough, evenly-textured bluish limestone, blue clay, some reddish sandstone, and conglomerate. The limestones are very thick-bedded in the south, and somewhat less so in the north. In the northern part of Texas sandstones become more important and thicker, especially in the lower part of the formation. The average thickness of the whole formation is 800 to 900 feet.

The Canyon formation is exposed in a somewhat narrow belt beginning in the south in the vicinity of Brady (McCulloch County) and extending toward the north-northeast to the foot of the Cretaceous hills northeast of the Pecan Bayou. From the north side of this range it continues to form a belt in Eastland, Stephens, Palo Pinto, Young, Jack and Wise counties; then it disappears below the Cretaceous rocks.

The Canyon formation Drake subdivided in his Colorado River section into twelve parts from below upward, as follows: (1) Coral Limestone bed; (2) Rochelle Conglomerate; (3) Brownwood bed; (4) Adams Branch bed; (5) Cedarton bed; (6) Clear Creek bed; (7) Bed Number 7; (8) Chert bed; (9) Hog Creek bed; (10) Home Creek bed; (11) Bluff Creek bed; (12) Camphophyllum bed.

In the northern region several coal seams occur in the Canyon. This formation is of some importance also on account of the numerous springs, where waters accumulate in the limestones.

The Cisco Formation

This formation is composed of beds of blue clay, more or less shaly; of sandstone, usually conglomeratic or even of real conglomerate; and of limestone occurring in thin and isolated beds. The limestone is generally hard and irregular in texture. In the Central Mineral Region this formation contains more beds of limestone than it does in the southern part of north Texas. Farther toward the north the calcareous material diminishes still more, and north of Young County it disappears entirely, or is represented only by irregular nodular masses of earthy limestone in a matrix of clay. With the thinning of the limestone beds, the shales and sandstones gain in thickness toward the north. In the southern part, up to Stephens County, the shales show principally a bluish color and the sandstones are gray; farther north these colors gradually change into red until this color predominates in the vicinity of Red River. There the formation is mainly composed of red or gray sandstone, red clay and sandy shales with few beds of blue and bluish to grayish white sandstone.

The total thickness of the Cisco formation is perhaps about 800 feet both in the central region and in the north; in the extreme northern region the thickness cannot be exactly determined on account of the impossibility of finding a precise division line between the Cisco and the overlying Wichita formation. Both are there lithologically quite similar.

The Cisco formation is exposed in a broad belt, beginning at the south on the Brady Creek (Concho and McCulloch counties); toward the north it is interrupted by a strip of overlying Cretaceous in the Brady Mountains. In the northern foot of these it reappears and continues toward the north-northeast to Callahan County, where it is again covered by the Cretaceous northeast of the Pecan Bayou. North of this Cretaceous outlier it forms a broad zone from Callahan County through Shackelford, Stephens, Young, Jack, Archer, Clay and Montague counties; and in this latter county it becomes partly covered by Cretaceous rocks.

The Cisco was found by Drake to have the following divisions in his Colorado River section named in the order from below upward: (1) Trickham bed; (2) Bellerophon bed; (3, 4) Speck Mountain beds; (5) Lohn bed; (6) Parks Mountain Conglomerate and Sandstone bed; (7) Chaffin beds; (8) Waldrip beds; (9) Saddle Creek bed; (10) Camp Creek bed; (11) Coon Mountain bed; (12) Stockwether bed; (13) Bed Number 13; (14) Camp Colorado bed; (15) Watts Creek bed; (16) Horse Creek bed; (17) Santa Anna bed; (18) Bed Number 18; (19) Santa Anna Branch bed.

In the Cisco formation occur the most important coal seams of the Texas Carboniferous; one, the Chaffin seam, is found about 200 to 250 feet above the base. It is known only in the south. The main seam lies somewhat above the middle of the formation and is found in the south as well as in the north.

Trans-Pecos Texas

The Pennsylvanian of Trans-Pecos Texas has been described under seven different names. In Presidio County are the Cieneguita and the Alta beds. In El Paso and Hudspeth counties is the Hueco, and in Brewster County have been distinguished the Tesnus, the Dimple, the Haymond, and the Gaptank. The Tesnus and the Dimple probably correspond in age to the Cieneguita, and the Haymond is possibly to be correlated to a part of the Alta beds.

The higher part of the Pennsylvanian is not developed everywhere in the Trans-Pecos region. It has been eroded in several places so that the Permian rests directly on the lower Pennsylvanian. While the lower Pennsylvanian of that part of the country everywhere is rather intensely folded, the upper portion of the Pennsylvanian seems to be only gently folded. In that respect it has the structural relations characteristic of the Permian.

Southern Trans-Pecos

The Tesnus Formation

This formation occurs in the Marathon region, where it unconformably overlies the Santiago chert. At the base of the Tesnus, named by Baker, is the Rough Creek shale member, 865 feet in thickness, of hard, compact and brittle, dark green, occasionally black, shale. Above are sandstone, shale, chert, and a few thin lenticular layers of conglomerate. The sandstones are from soft to highly indurated, thin-bedded to massive, in color predominantly dark, dirty green or rusty brown. The shales are dark, dirty green or black, well laminated when more clayey, roughly jointed when more sandy. Dense, dull-lustred chert occurs in thin layers and is prevailingly black or brownish-black in color. The Tesnus formation has a thickness of 3,370 feet. The only fossils known are a few poorly-preserved remains of land plants.

The Dimple Formation

This is also found in the Marathon region. It consists of alternating beds of dark gray limestones, black chert and black shales, with a few beds of chert conglomerate. The limestones carry a few marine fossils. The thickness is 925 feet. The formation rests upon the Tesnus. It has been named by Udden.

The Haymond Formation

The Haymond formation of the Marathon region overlies the Dimple and consists of thin-bedded greenish sandstones alternating with green and black clays with a few beds of dark brown finely conglomerate limestone containing marine fossils. The minimum thickness known is about 500 feet but on the northwest side of the Marathon Basin the total thickness is probably greater.

Cieneguita Beds

Other Pennsylvanian rocks have been found in very few places in this region. It seems best developed in the region of Shafter in Presidio County. There Udden has subdivided it into two groups, the basal Cieneguita beds, and above these the Alta beds. The latter are divided into the Dark Shales and the Yellow Sand.

The Cieneguita beds form the base of the Pennsylvanian and rest in one place on a granite. They consist of a series of dark to black shales alternating with dark limestones, conglomerates and heavy lenticular masses of a clastic rock composed of siliceous fragments cemented by calcareous clay (mortar rock). The shale predominates. Locally, some layers of black chert occur. This whole series of rocks is at least 1,000 feet thick. It outcrops north of Shafter between Cibolo Creek and some of its western tributaries, east and southeast of the Ojo Bonito and the Cieneguita ranches.

Alta Beds

The Alta beds, which rest on the Cieneguita beds, show a thickness of about 3,500 feet. They consist of some dark shales below and some yellow sands above.

The dark shales consist of sharply bedded layers of silt, clay, and some sand, with layers of coarser and more purely sandy material. The thickness of this series is approximately 2,000 feet.

The yellow sand consists of a soft, occasionally almost crumbling, bluish-gray sandstone of fine texture. It is a coarse silt of well assorted quartz grains. The thickness of this series is about 1,500 feet.

The Gaptank Formation

Less well known is the Upper Pennsylvanian southeast of the Glass Mountains, but its occurrence there cannot be doubted. It has been named Gaptank by Udden and it consists at the base of conglomerates alternating with limestones, sandstones and shales; in the middle part of shales interbedded with limestone; and in the upper portion is mainly composed of several masses of limestone separated by shaly and sandy material. The thickness of the whole formation surpasses 1,500 feet. It probably corresponds to the highest portion of the Pennsylvanian of central Texas —the Cisco formation. The Gaptank formation has been found at Gaptank, 24 miles northeast of Marathon; it extends for a short distance to the southeast of this point and about 15 miles to the southwest.

Northern Trans-Pecos

Much better developed is the Upper Pennsylvanian in the Northern Trans-Pecos region, north of the Kansas City, Mexico and Orient railroad, and the Southern Pacific railroad, between Pecos and El Paso. It is developed in a manner entirely different from that of the rocks of the same age in southern Trans-Pecos and in central Texas, and it is probably intimately connected with the Upper Pennsylvanian of the west of the United States. The Pennsylvanian in this part of the Trans-Pecos region has been called the Hueco formation, by G. B. Richardson.

The Hueco Limestone

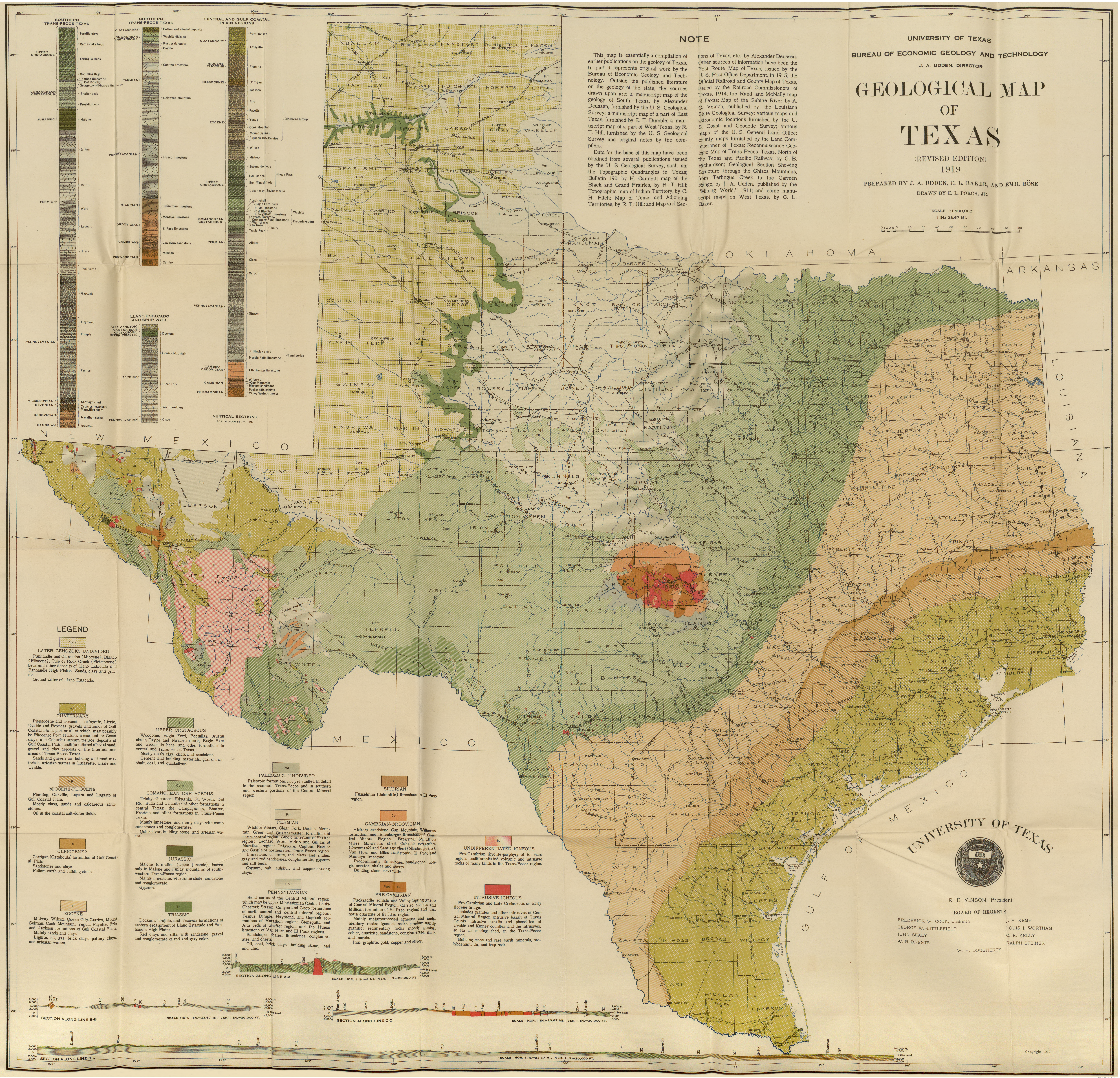
This formation consists almost entirely of a gray, hard, thick- to thin-bedded limestone, which contains very little magnesia, or none at all. At the base of this limestone generally occur yellow to brown and purple sandstones, and conglomerates, as well as some gray and yellowish shales. The entire formation is at least 5,000 feet thick. It is known in the Franklin Mountains immediately north of El Paso; in the Finlay and Hueco mountains east of El Paso; in the Cornudas, Diablo and Baylor mountains north and northwest of Van Horn; and in the Wylie Mountains, southeast of that town. It is not known where the Hueco formation terminates toward the south. The upper part of the Hueco is probably Permian.

PERMIAN

Central and North Texas

The Permian of this region belongs to the Red Bed phase and is the southern continuation of the Permian Red Beds of the Central Great Plains and eastern Rocky Mountain foothill area. In north-central Texas the Permian exposure is bounded on the north by the Red River; on the east and south by the Cisco exposure and by the Comanchean Cretaceous; and on the west by the Triassic, the Comanchean and the Cenozoic deposits covering the Llano Estacado and Panhandle High Plains. On the west of the Llano Estacado Permian Red Beds and the Triassic form the lowlands of the Pecos Valley and extend westward nearly to the foot of the easternmost ranges of Trans-Pecos Texas. Two small exposures of the Permian Red Beds also appear along the valley of the Canadian River in Oldham and Potter counties where they form the cores of low anticlines.

The Permian of the north-central area was divided by Cummins into the Wichita-Albany, the Clear Fork, and the Double Mountain, the first mentioned being the oldest and the last mentioned the youngest. Gould has divided the



UNIVERSITY OF TEXAS

BUREAU OF ECONOMIC GEOLOGY AND TECHNOLOGY

J. A. UDDEN, DIRECTOR

GEOLOGICAL MAP OF TEXAS

(REVISED EDITION)

1919

PREPARED BY J. A. UDDEN, C. L. BAKER, AND EMIL BÖSE

DRAWN BY E. L. PORCH, JR.

SCALE, 1:1,500,000

1 IN.; 23.67 MI.

NOTE

This map is essentially a compilation of earlier publications on the geology of Texas. In part it represents original work by the Bureau of Economic Geology and Technology. Outside the published literature on the geology of the state, the sources drawn upon are: a manuscript map of the geology of South Texas, by Alexander Deussen, furnished by the U. S. Geological Survey; a manuscript map of a part of East Texas, furnished by E. T. Dumble; a manuscript map of a part of West Texas, by R. T. Hill, furnished by the U. S. Geological Survey; and original notes by the compilers.

Data for the base of this map have been obtained from several publications issued by the U. S. Geological Survey, such as: the Topographic Quadrangles in Texas; Bulletin 190, by H. Gannett; map of the Black and Grand Prairies, by R. T. Hill; Topographic map of Indian Territory, by C. H. Fitch; Map of Texas and Adjoining Territories, by R. T. Hill; and Map and Sections of Texas, etc., by Alexander Deussen. Other sources of information have been the Post Route Map of Texas, issued by the U. S. Post Office Department, in 1915; the Official Railroad and County Map of Texas, issued by the Railroad Commissioners of Texas, 1914; the Rand and McNally map of Texas; Map of the Sabine River by A. C. Veatch, published by the Louisiana State Geological Survey; various maps and astronomic locations furnished by the U. S. Coast and Geodetic Survey; various maps of the U. S. General Land Office; county maps furnished by the Land Commissioner of Texas; Reconnaissance Geologic Map of Trans-Pecos Texas, North of the Texas and Pacific Railway, by G. B. Richardson; Geological Section Showing Structure through the Chisos Mountains, from Terlingua Creek to the Carmen Range, by J. A. Udden, published by the "Mining World," 1911; and some manuscript maps on West Texas, by C. L. Baker.

LEGEND

Cen

LATER CENOZOIC, UNDIVIDED

Panhandle and Clarendon (Miocene), Blanco (Pliocene), Tule or Rock Creek (Pleistocene) beds and other deposits of Llano Estacado and Panhandle High Plains. Sands, clays and gravels.

Ground water of Llano Estacado.

Qt

QUATERNARY

Pleistocene and Recent. Lafayette, Lizzie, Uvalde and Reynosa gravels and sands of Gulf Coastal Plain, part or all of which may possibly be Pliocene; Port Hudson, Beaumont or Coast clays, and Columbia stream terrace deposits of Gulf Coastal Plain; undifferentiated alluvial sand, gravel and clay deposits of the intermontane areas of Trans-Pecos Texes.

Sands and gravels for building and road materials, artesian waters in Lafayette, Lizzie and Uvalde.

MPl

MIOCENE-PLIOCENE

Fleming, Oakville, Lapara and Lagarto of Gulf Coastal Plain.

Mostly clays, sands and calcareous sandstones.

Oil in the coastal salt-dome fields.

Ol

OLIGOCENE?

Corrigan (Catahoula) formation of Gulf Coastal Plain.

Sandstones and clays.

Fullers earth and building stone.

E

EOCENE

Midway, Wilcox, Queen City-Carrizo, Mount Selman, Cook Mountain, Yegua, Fayette, Frio and Jackson formations of Gulf Coastal Plain.

Mainly sands and clays.

Lignite, oil, gas, brick clays, pottery clays, and artesian waters.

K

UPPER CRETACEOUS

Woodbine, Eagle Ford, Boquillas, Austin chalk, Taylor and Navarro marls, Eagle Pass and Escondido beds, and other formations in central and Trans-Pecos Texas.

Mostly marly clay, chalk and sandstone.

Cement and building materials, gas, oil, asphalt, coal, and quicksilver.

Com

COMANCHEAN CRETACEOUS

Trinity, Glenrose, Edwards, Ft. Worth, Del Rio, Buda and a number of other formations in central Texas; the Campagrande, Shafter, Presidio and other formations in Trans-Pecos Texas.

Mainly limestone, and marly clays with some sandstones and conglomerates.

Quicksilver, building stone, and artesian water.

Jr

JURASSIC

Malone formation (Upper Jurassic), known only in Malone and Finlay mountains of southwestern Trans-Pecos region.

Mainly limestone, with some shale, sandstone and conglomerate.

Gypsum.

Tr

TRIASSIC

Dockum, Trujillo, and Tecovas formations of eastern escarpment of Llano Estacado and Panhandle High Plains.

Red clays and silts, with sandstone, gravel and conglomerate of red and gray color.

Pal

PALEOZOIC, UNDIVIDED

Paleozoic formations not yet studied in detail in the southern Trans-Pecos and in southern and western portions of the Central Mineral region.

Pm

PERMIAN

Wichita-Albany, Clear Fork, Double Mountain, Greer and Quartermaster formations of north-central region; Cibolo limestone of Shafter region; Leonard, Word, Vidrio and Gilliam of Marathon region; Delaware, Capitan, Rustler and Castile of northeastern Trans-Pecos region

Limestone, dolomite, red clays and shales, gray and red sandstones, conglomerate, gypsum and salt beds.

Gypsum, salt, sulphur, and copper-bearing clays.

Pn

PENNSYLVANIAN

Bend series of the Central Mineral region, which may be upper Mississippian (Saint Louis-Chester); Strawn, Canyon and Cisco formations of north central and central mineral regions; Tesnus, Dimple, Haymond, and Gaptank formations of Marathon region; Cieneguita and Alta beds of Shafter region; and the Hueco limestone of Van Horn and El Paso regions.

Sandstones, shales, limestones, conglomerates, and cherts.

Oil, coal, brick clays, building stone, lead and zinc.

S

SILURIAN

Fusselman (dolomitic) limestone in El Paso region.

Co

CAMBRIAN-ORDOVICIAN

Hickory sandstone, Cap Mountain, Wilberns formation, and Ellenburger limestone of Central Mineral Region. Brewster, Marathon series, Maravillas chert, Caballos novaculite (Devonian?) and Santiago chert (Mississippian?); Van Horn and Bliss sandstones, El Paso and Montoya limestone.

Predominantly limestones, sandstones, conglomerates, shales and cherts.

Building stone, novaculite.

Pcc Pc

PRE-CAMBRIAN

Packsaddle schists and Valley Spring gneiss of Central Mineral Region; Carrizo schists and Millican formation of El Paso region; and Lanoria quartzite of El Paso region.

Mainly metamorphosed igneous and sedimentary rocks; igneous rocks predominantly granitic; sedimentary rocks mostly gneiss, schist, quartzite, sandstone, conglomerate, shale and marble.

Iron, graphite, gold, copper and silver.

Iu

UNDIFFERENTIATED IGNEOUS

Pre-Cambrian rhyolite-porphyry of El Paso region; undifferentiated volcanic and intrusive rocks of many kinds in the Trans-Pecos region.

Ii

INTRUSIVE IGNEOUS

Pre-Cambrian and Late Cretaceous or Early Eocene in age.

Includes granites and other intrusives of Central Mineral Region; intrusive basalt of Travis County; intrusive basalts and phonolites of Uvalde and Kinney counties; and the intrusives, so far as distinguished, in the Trans-Pecos region.

Building stone and rare earth minerals, molybdenum, tin; and trap rock.

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upper or Double Mountain Permian Red Beds in the valley of the Canadian River into the Greer formation below and the Quartermaster formation above.

The Wichita-Albany

The Wichita formation is from 1,000 to 1,500 feet in thickness. It outcrops in Clay, Wichita, Baylor, Wilbarger, Archer, Young, and Throckmorton counties, and farther west underlies more recent strata. The Wichita consists of red, bluish, and gray-white sandstones, red concretionary clays, occasional blue shales, and clay-ball conglomerate. The dominant color is red. To the southwest the Wichita is believed to grade into the marine clays and limestones of the Albany. The Albany clays and shales are blue-black and gray, and the limestone, more important toward the top of the formation, is generally hard, compact, and massively bedded. The Albany outcrops in Shackelford, Brown, Throckmorton, Baylor, Young, Coleman, Runnels, Concho, McCulloch, and Mills counties.

The Albany was divided by Drake in his Colorado River section into fifteen units, named in the order from below upward, as follows: (1) Coleman Junction bed; (2) Los Creek bed; (3) Hordes Creek bed; (4) Indian Creek bed; (5) Bed Number 5; (6) Coleman bed; (7) Elm Creek bed; (8) Bed Number 8; (9) Jagger Bend bed; (10) Valera bed; (11) Bead Mountain bed; (12) Bed Number 12; (13) Grape Creek bed; (14) Talpa bed; (15) Paint Rock bed.

The Clear Fork

The Clear Fork is about 1,900 feet thick. It consists of red and blue clays, sandy shales, limestones, sometimes dolomitic, some white, red, and spotted sandstones, gypsum, and clay-ball conglomerate. Underneath the Llano Estacado, the Red Beds are apparently in part or wholly replaced by limestones alternating with layers of gypsum. The Clear Fork outcrops in Wilbarger, Baylor, Throckmorton, Haskell, Jones, and Shackelford counties.

The Double Mountain

The Double Mountain is about 2,000 feet thick. The formation consists of sandstones, sandy shales, limestones, often dolomite, red and bluish clays, and thick beds of gypsum and rock salt. The Double Mountain outcrops in an area some 200 miles long from north-northeast to south-southwest, and from fifty to a hundred miles wide, roughly included between the counties of Wilbarger and Hall to the north, and Tom Green and Reagan on the south. It also underlies the easternmost part of the Panhandle, where it is mostly covered by the Triassic.

Southern Trans-Pecos

The Permian has a wide distribution in western Texas. It is now recognized, with certain interruptions, from near the Mexican border up to New Mexico. We can distinguish three different areas where the Permian has been studied more or less in detail—the Shafter region, the Marathon region, and the region of the Delaware and Guadalupe mountains.

The Shafter Region, Presidio County

The Cibolo Beds

The rocks which represent the Permian have been called by Udden the Cibolo Beds, and they have been subdivided by the same author from below to above in: Transition beds, Lower Brecciated Zone, Zone of Sponge Spicules, Thin-bedded Zone, and Yellow Limestone.

Transition Beds. Gray marly shale with lenticular ledges of organic and siliceous sand. Their thickness is about 100 feet.

Lower Brecciated Zone. Grayish-white limestone in heavy ledges often thoroughly brecciated. The thickness is about 133 feet.

Zone of Sponge Spicules. In the lower part, this consists of thinner bedded limestone. Above it becomes siliceous and changes into pure sandstone. The thickness of this bed is 85 feet.

Thin-bedded Zone. Dark, evenly bedded and compact limestone, including some sandy strata. The limestone contains cherty material which weathers out in rusty edges of plates of irregular shape, or porous spherical shells and nodules. Much of the rock is bedded in uniformly thin ledges; occasionally the ledges thicken lenticularly. Thickness, about 470 feet.

Yellow Limestone. Hard, yellow, siliceous and dolomitic limestone, showing bedding planes only in the lower part, while higher up the stratification becomes indistinct. Thickness, about 650 feet.

This series has been observed on Cibolo Creek near the Chinati Mountains west of Shafter.

The Marathon Region

The Permian is very well developed in the Glass Mountains. It has been subdivided by Udden into seven formations, which are, from below to above, the Wolfcamp, the Hess, the Leonard, the Word, the Vidrio, the Gilliam, and the Tessey. The lower formations are found in the southern and southeastern hills, while the upper ones—the Vidrio and Gilliam formations—occupy the center and the whole northern slope. Towards the southwest, the continuation of this Permian is found in the Altuda Mountain and south of it, in the Ord Mountain Range. Toward the north we find an isolated outlier in the Sierra Madera. The highest parts of the Permian are covered unconformably by the Comanchean Cretaceous.

The Wolfcamp Formation

This formation consists of about 500 feet of shales with some layers of limestones, the shales varying in color from black to gray and greenish-gray. The limestones are largely shell-breccias which are in part conglomeratic and change to calcareous sandstones. The formation is unconformable with the overlying Hess sediments. The Wolfcamp is best developed in the base of the Glass Mountain Escarpment some six miles east from Leonard Mountain.

The Hess Formation.

This consists of a little more than 2,000 feet of limestones with some thin beds of shales and limestones and a well defined basal conglomerate. The bedding planes in this formation are regular and well marked and, excepting the basal part, it is free from coarse material. Most of its limestones are largely foraminiferal. The Hess forms the main south escarpment of the Glass Mountains from the Hess Ranch nearly to Gaptank.

Leonard Formation

The upper part is composed of thinly laminated yellowish sandstone interbedded with layers of gray limestone, yellow chert and gray shales. The lower part consists of heavy and thinly bedded gray limestone, in part conglomeratic or containing pebbles of different size. At the base, shales and soft sandstones are interbedded with a dark gray limestone. The thickness of the entire series is nearly 1,800 feet. The section characterized here has been measured in Leonard Mountain and north of it. Farther to the east near Word's Ranch, the series is much more calcareous, in the upper and middle part; the thickness is more than 2,300 feet. Toward the west of the first mentioned section, the shales begin to predominate, while the limestone is reduced in thickness. At the base of this formation is a conglomerate from 20 to 200 feet thick, and this unconformably overlies the Pennsylvanian.

Word Formation

In the upper part this is composed of thin and thick-bedded gray and yellow to reddish limestone, in part dolomitic, containing chert concretions with some interbedded strata of sandstone (about 380 feet); below this we find some 120 feet of yellow sandstone, in part laminated. The lowest part of this formation consists of 120 feet of heavy bedded gray limestone, with chert concretions. The entire thickness of this formation is approximately 600 feet.

Vidrio Formation

This series is composed of a very uniform, dark to light gray, dolomitic limestone, or dolomite, with very few layers of pure limestone. The dolomite contains considerable chert in irregular form. In the uppermost part we find one or two beds of reddish-brown sandstone about 4 feet thick. The entire thickness of this formation is about 2,000 feet.

Gilliam Formation

This series is composed of gray, light colored and reddish limestone and dolomite; both are frequently brecciated. In the upper part the rock is nearly massive, or at least, bedding planes are very dim. In the middle the limestone shows thick lenticular beds while in the lower part it is decidedly thin-bedded. At the base we find thicker layers of reddish dolomite alternating with thinly laminated layers of the same rock and with thin strata of yellowish marly sandstone. The thickness of this enormous mass is 2,600 feet, in Gilliam Canyon.

The Tessey Formation

This is the highest formation of the Permian seen in the Glass Mountains. It resembles the Vidrio in its general characteristics, consisting of thick layers of mostly dolomitic limestone. It underlies the Comanchean in the northwest foothills of the Glass Mountains. In places this formation has well marked bedding planes. A considerable part of the rock is only slightly dolomitic and some layers are finely oolitic. The maximum thickness of this formation appears to be about 1,400 feet.

Additional Notes on the Permian in the Southern Trans-Pecos Region

The Permian is also developed in two more regions, one to the south of Ord Mountain and the other to the east and north of Ord Mountain. Both are situated on the south of the Southern Pacific railroad between the stations of Marathon and Alpine. The lower part of the Permian is developed only in the section south of Ord Mountain. According to Baker, the Permian in the region south of the Southern Pacific railroad may be subdivided as below: The oldest member of the series overlies tilted early Pennsylvanian. The Permian begins with:

1. Limestone conglomerate, massive to thin-bedded, with some thin flaggy beds of rather arenaceous limestone, the conglomerate becoming gradually less in amount toward the top and the size of the pebbles decreasing. Thickness, several hundred feet.

2. Thin beds of light gray chert interbedded with light gray limestone.

3. Above this is a mass of shale, thin-bedded, flaggy sandstones, and gray, thin-bedded limestone, weathering brownish yellow. Thickness, at least 1,000 feet.

Between this and the next number there is a gap in the section.

4. On the top we find a massive, brown, medium-grained, calcareous sandstone, obscurely bedded. The greatest thickness is about 250 feet, but in some places it disappears altogether.

To the east and north of Ord Mountain the Permian is like the series described above. According to Udden the following series is found in the Altuda Mountain.

2. The lowest part of Altuda Mountain section, as seen south from the mountain, consists of shales, sandstones and limestones with a conglomerate near the middle. Thickness, about 2,000 feet.

3. Above this we find a thin-bedded limestone containing shaly and sandy strata.

4. The highest part of the series is formed by a cream-

colored limestone, mostly dolomite, without bedding planes, and somewhat crystalline in texture. This is the Vidrio limestone of the Glass Mountains. Thickness, about 600 feet.

Northern Trans-Pecos

The Delaware and Guadalupe mountains extend in an approximately north-south direction through Culberson County from the Texas and Pacific railroad to the boundary of New Mexico. The Delaware Mountains form the southern range, the Guadalupe Mountains the northern; the latter extending far into New Mexico.

The Permian, which composes both of these ranges as well as the hilly country to the east about as far as the boundary of Reeves County, has been subdivided by G. B. Richardson into four different formations: Delaware Mountain formation, Capitan limestone, Castile gypsum and Rustler formation. The latter is the highest member of the series.

Manzano Group

At the base of the western fault scarp of the Guadalupe Mountains, a formation of mostly thin-bedded cherty blue limestone, in places bituminous, is overlain by a small thickness of more heavily-bedded limestone. The whole is approximately 1,000 feet in thickness, the base not being exposed. This limestone probably represents the upper portion of the Yeso formation and the lower portion of the San Andreas limestone, the two upper formations of the Manzano Group of southeastern New Mexico. This limestone series is unconformably overlain by the Delaware Mountain formation.

Delaware Mountain Formation

This formation is composed of an alternation of gray and bluish limestone with white and brown sandstone. Toward the north of the Delaware Mountains the formation becomes more sandy; toward the south the limestone increases in amount. In the Apache Mountains the formations consist entirely of massive whitish-gray limestone. The maximum thickness is at least 2,200 feet. The Delaware formation forms a broad zone composing the Delaware, the Apache Mountains, the lower part of the Guadalupe Mountains, and part of the Wylie Mountains. Recent observations by C. L. Baker show that in the southern Guadalupe Mountains, at Bone Spring, just south of the Texas line, the Delaware Mountain formation unconformably overlies the San Andreas limestone of New Mexico, probably equivalent to the upper Hueco. The Delaware Mountain thins rapidly northward from Guadalupe Point and comes to an end before the New Mexico boundary is reached.

Capitan Limestone

This formation is composed of a massive white limestone remarkably homogeneous in appearance. The entire thickness cannot be determined, but it is at least 1,700 feet. It is known only in the Guadalupe Mountains and extends into New Mexico. To the east and north the Capitan limestone changes into the Red Beds of the Pecos Valley, a series of red sandstone, shales, limestone, gypsum and rock salt. The Capitan limestone may also occur in the Apache Mountains, south of the Delaware Mountains.

Castile Gypsum

This formation is in great part composed of a massive, white, granular gypsum but interbedded with it are thin beds of gray and yellow limestone and dolomite as well as thicker beds of the same rock and considerable masses of gray, red and green shales and marls. The thickness of this formation is not exactly known, but two deep wells near Rustler Springs show that it cannot be less than 1,000 feet. The Castile Gypsum forms a band about 15 miles broad, west of the hills composed of the Rustler limestone; toward the north the Castile Gypsum is found also east of the Rustler Hills, so that the breadth of the zone increases to about 30 miles near the boundary of New Mexico. Some isolated exposures are found on the west side of the Delaware Mountains. As far as known the Castile Gypsum rests everywhere unconformably on the Delaware formation. In Culberson County some shale in this formation is sulphur-bearing.

Rustler Formation

Compact, fine-textured, gray dolomitic limestone and dolomite, generally quite heavy-bedded, compose this formation. At the base there is in most places a considerable mass of light pink or yellowish brecciated limestone. In the northern part of the region some yellow sandstone alternating with limestone is developed below the brecciated limestone. The thickness of the Rustler formation has not been determined, but it must be at least several hundred feet. The Rustler formation appears in a series of low hills extending from a point about 12 miles north of Kent to the boundary of New Mexico.

Correlation of the Permian Subdivisions in Trans-Pecos Texas

The subdivisions of the Permian in western Texas are all more or less provisional and local; even a definite correlation between these local subdivisions cannot be made until they are studied in detail. Nevertheless, we are able to correlate them even now to a certain degree, as follows. In the Shafter Region the transition beds, lower brecciated zone, zone of sponge spicules, thin-bedded zone and yellow limestone correspond certainly to the Leonard and perhaps the Word formations of the Glass Mountains.

In the Ord Mountains and vicinity, Nos. 1 and 2 correspond probably to the Leonard formation; No. 3 to the Word formation; while No. 4 may belong also to the Word formation of the Glass Mountains.

In the Altuda Mountain, No. 2 belongs to the Leonard formation, No. 3 to the Word formation, No. 4 represents the lower part of the Vidrio formation. The upper part of this limestone has been eroded before the deposition of the Cretaceous.

In the entire Marathon Basin, the Permian rests unconformably on the Pennsylvanian; in the northern portion on the Gaptank formation with equal strike and dip, and farther south on different members of the strongly folded part of the Pennsylvanian.

More difficult still is the comparison of the subdivisions of this southern area with those of the northern one. It is quite safe to correlate the Vidrio formation with the Capitan limestone, although the former one has very few fossils. The Gilliam formation probably belongs to some higher part of the Permian, representing, perhaps, the Castile Gypsum and Rustler limestone. It is difficult to say how much of the two lower subdivisions of the Glass Mountains corresponds to the Delaware formation of the northern region, but certainly the Word formation represents at least part of it.

These conclusions are set forth in tabular form below:

PROBABLE CORRELATION OF THE PERMIAN SUBDIVISIONS IN WEST TEXAS

Shafter region	Ord Mountain and vicinity	Glass Mountains	Delaware-Guadalupe Mountains
Yellow limestone	1. Vidrio formation	Tessey formation Gilliam formation Vidrio formation	Rustler limestone
	2. Sandstones and limestones	Word formation	Capitan limestone / Castile gypsum / Delaware formation
Thin-bedded zone Zone of Sponge Spicules Lower brecciated zone Transition beds	3. Shales, sandstones	Leonard formation Hess formation Wolfcamp formation	Hueco formation
	4. Limestone conglomerate and thin-bedded or flaggy limestone		
Pennsylvanian (Alta and Cieneguita beds)	Pennsylvanian	Gaptank formation	

MESOZOIC

All of the Mesozoic systems—the Triassic, the Jurassic and the Cretaceous—are represented in Texas. They are not of equal importance, the Jurassic being known only at one point, and the Cretaceous having a distribution by far larger than either of the other two.

TRIASSIC

N. F. Drake has described the *Dockum beds*, and has proved that these are of Triassic age. These outcrop in a belt under the east escarpment of the Llano Estacado and extend westward into New Mexico. He describes the Dockum beds as consisting of a lower bed of sandy clay from 0 to 150 feet thick; a middle bed of sandstone, mostly weathering white, from 0 to 235 feet thick; and an upper bed of sandy clay and some sandstone from 0 to 300 feet thick. The sandstones are in many places micaceous and fissile. The irregular thinning and thickening of these beds, independently of each other, shows that the conditions of deposition differed locally and contemporaneously, and Drake remarks that his three divisions do not absolutely represent geological horizons. The greater part of these beds is red. Silicified and lignitized wood is common, especially in the sandstones, and fossil remains of reptiles have been found in many places. The sands and conglomerates are frequently water-bearing. Oxide of manganese is in places found in association with silicified wood. It occurs only in small quantities.

In the valleys of the uplands in the Panhandle, Gould has differentiated a series of like sediments into two formations, the lower of which he designates as the *Tecovas* and the upper as the *Trujillo beds*. Baker, who recently studied the Triassic in the Panhandle, states that the Triassic deposits can usually be distinguished from the underlying Permian redbeds by (1) the gray and brown color of the sandstones; (2) the variegated, maroon, wine-color, white, lavender, and yellow color predominating in the shales; and

(3) by the extensive development of cross-bedding and local unconformities. None of these characteristics is found in the Permian.

The Dockum Beds are Upper Triassic in age, of the same age as the Keuper in Europe.

JURASSIC

Until now, Jurassic rocks are known only near Malone and Finlay, Hudspeth County, stations on the Southern Pacific railroad. The rocks of this formation are principally blue and gray limestone interbedded with shales, sandstones and conglomerates. At the base there are several beds of gypsum. The entire thickness as far as can be observed is 1,500 to 2,000 feet. The Jurassic composes several hills, the Malone Mountains, southeast of Finlay.

The rocks described here, known as the Malone formation, represent only the higher parts of the upper Jurassic, the lower part, as well as the entire middle Jurassic and the Liassic, being unknown in Texas.

CRETACEOUS

The Cretaceous is perhaps the most important formation of Texas, on account of its wide distribution. It covers a great part of eastern and central Texas and is well represented in the west. Nearly everywhere it rests unconformably on older formations, especially the Carboniferous (east and central Texas) and the Permian (west Texas). Only in one locality (Malone, in west Texas) according to our present knowledge, there seems to exist an uninterrupted sedimentary series from the upper Jurassic to the middle part of the Cretaceous.

In Texas the Cretaceous has been subdivided into two great series: The Comanchean Cretaceous and the Upper Cretaceous. The former comprehends every horizon between the Jurassic (or the older formations, Carboniferous, Permian, Triassic) and the Eagle Ford shales. The Upper Cretaceous comprises the strata between the Comanchean and the Tertiary. The greatest thickness of the two series is more than 5,000 feet, the Comanchean sediments measuring some 1,500 feet and the Upper Cretaceous some 3,000 feet.

COMANCHEAN CRETACEOUS

The Comanchean has been subdivided into three parts, the Trinity, the Fredericksburg, and the Washita divisions, the first of which is the lowest, the last the highest. In describing the Comanchean, we shall use the names introduced by R. T. Hill.

East and Central Texas

Trinity Division

The lower Trinity beds in east Texas are deposits formed near an ancient coast-line, and consist of conglomerates and sands. Higher up, these give place to clays, marls and limestones. The Trinity division (or Bosque division, according to Taff) has been subdivided into three parts, the lowest of which is the Basement sands. Upon these follows the Glenrose formation. The highest part has been named the Paluxy formation. These three subdivisions are by no means of the same stratigraphical value; they are not constant. The Basement sands are much thicker in the northern part of eastern Texas and there they represent what farther south is known as Glenrose formation. Thus, while in the south in the Comanchean sea a marly limestone was deposited, in the northern region the conditions were such that only sands accumulated. Similar are the relations between the Paluxy sands and the Glenrose. The former exist only in the north, while in the south they are represented by the upper beds of the Glenrose.

Basement Sands. The Basement sands are composed of conglomerate beds at the bottom, grading up into pack-sands that become finer and more calcareous upward, until they pass into arenaceous clays and limestone. The sands are generally white or yellowish. The argillaceous material is green, purple, red and bluish. The thickness of this formation averages about 100 to 120 feet but varies extremely. In some places it is only fifty feet. In the northernmost part of the State it may be 300, and even 400 feet. The Basement sands are known to extend from Burnet County to the northern border of the State with a long, although interrupted, western deflection from Brown County to the Llano Estacado. The average width of the belt where these sands outcrop is several miles, but in the northern counties we often find outliers of the conglomerates and sands on the Paleozoic area far to the west of this belt.

Travis Peak. South of Burnet County the Basement sands have been called the Travis Peak formation. This consists principally of conglomerates, sand and some bluish shale in the lower part, and of calcareous sandstone, marly and arenaceous limestone with bands of conglomerate in the higher part. The entire thickness of the formation is about 250 to 300 feet. It extends around the eastern and southern limit of the Central Mineral Region, covering the Paleozoic rocks. This formation has been subdivided from below upward, into the *Sycamore sands, Cow Creek beds* and *Hansell sands,* but these are of rather local importance.

Glenrose Formation. The Glenrose formation, also called "Alternating Beds," is composed of even-bedded, argillaceous, chalky limestones interbedded with thin beds of marly arenaceous clay, all gray, white or yellowish in color. The Glenrose formation is 300 to 400 feet thick, but it increases in thickness from west to east. Borings at Austin and San Marcos indicate a total thickness of about 600 feet.

In the extreme north of the State the Glenrose formation seems to be represented in part by sands belonging to the so-called *Antlers sand,* which represents the entire Trinity division. In the southern part of Wise County the Glenrose formation is found in its normal character and from there on it can be followed along the eastern escarpment of the Edwards Plateau near the region of the Balcones fault line down to southern Texas, where the formation has been identified in Edwards and Uvalde counties. Farther south, beyond the Mexican border, the character of the formation changes entirely into a hard limestone which usually cannot be distinguished from the overlying beds.

West of the Balcones fault line, the Glenrose formation is found in almost every large creek or river valley, nearly as far as the Trans-Pecos region.

Paluxy Formation. The Paluxy formation is composed of homogeneous, fine-grained, compact, but not indurated, sand, with some lenses of impure clay. It is often called packsand. In some places it becomes argillaceous toward the upper part. The formation attains a maximum thickness of about 100 feet. It is only found in the northern part of eastern Texas, and is especially well developed in Parker, Hood, Somervell, Erath, Bosque, Comanche, Hamilton and Coryell counties. From Wise County toward the north the Paluxy sands are continued in the Antlers sand which represents there the whole Trinity division.

The Paluxy sands thicken toward the north and thin out toward the south. They disappear entirely in Burnet and Travis counties and are not known to exist in the region between those points and the Rio Grande.

Fredericksburg Division

This division has been subdivided into three different parts from below upward: the Walnut clays, the Comanche Peak limestone, and the Edwards limestone. Only the upper of these seems to be entirely persistent, although it changes in thickness. In the northern part it is impossible to separate it from the underlying Comanche Peak, while in the south the Walnut clays are entirely missing.

Walnut Clays. The Walnut Clays (also called Exogyra texana beds and Texana beds) are composed of marly, laminated, yellow clays, alternating with thin semi-crystalline limestone flags. The thickness of these beds varies quite considerably. In the Bosque River valley it is only 25 to 40 feet thick; near Fort Worth, about 140 feet; at Comanche Peak, Hood County, approximately 120 feet. Nowhere does it show a thickness of more than 200 feet. The Walnut clays are generally well developed east of the Paleozoic area from the Colorado River up to the Red River. In some localities they are represented by soft limestone which cannot be distinguished from the Comanche Peak limestone. In the southern part of east Texas the Walnut clays seem to be represented by the lower beds of the Comanche Peak limestone.

Comanche Peak Formation. The Comanche Peak formation is composed of a heavy-bedded white marly limestone. Its thickness varies but is seldom more than 50 feet. The formation is well developed in the western half of the Lampasas Cut Plain between the Brazos and Colorado rivers. It extends from south of Fort Worth down to the Rio Grande.

Edwards Limestone. The Edwards limestone, also called *Caprina* and *Barton Creek* limestone, is not as argillaceous as the Comanche Peak formation. It is a pure white, hard limestone and contains many dark, irregular, flint nodules, in certain layers. The thickness of the Edwards limestone varies extremely. According to R. T. Hill it is only 4 feet on the Trinity River, while it is 600 feet at the Rio Grande. It should be taken into account that the Edwards limestone on the Rio Grande represents also the Georgetown beds, the Comanche Peak limestone, the Walnut clays, and possibly part of the Trinity division. Near Austin the thickness of the Edwards limestone is estimated to be about 300 feet. Toward the north it becomes much thinner.

In the northernmost part of the State it is impossible to separate the Comanche Peak from the Edwards limestone. Both together are represented by a white limestone of chalky texture, called Goodland limestone. This is only from 15 to 50 feet thick, and extends from Grayson County to the Red River and farther north into the State of Oklahoma.

The combined Comanche Peak and Edwards limestone, or Goodland limestone in the northern part of the State, represent one of the most widely distributed formations of the Texas Cretaceous. They are found from the northern border continuously down to the Rio Grande, forming steep cliffs and often the surface of wide tablelands. From central Texas they extend with interruptions toward the west until they are buried below the Llano Estacado, and farther south they form part of the surface of the enormous Edwards Plateau.

Washita Division

The term *Denison Beds* has been used by Hill to include all the deposits of the Washita Division of northern Texas above the Fort Worth Limestone. This division has been subdivided into a great many horizons, especially in the northern part of east Texas. In the south, conditions are more simple. There we distinguish from below upward: Georgetown limestone, Del Rio clays, Buda limestone. We shall discuss these southern subdivisions first, and then mention the corresponding northern horizons.

Georgetown Formation. The Georgetown formation is a grayish marly limestone with intercalations of marls and shales. The limestone is generally quite soft although there exist some harder layers, especially at the base and at the top. The formation is about 80 feet thick on the Colorado River; toward the south it seems to become thinner and on the Rio Grande the Georgetown has not yet been distinguished from the Edwards and Comanche Peak limestones. Toward the north the Georgetown is readily differentiated. It reaches, in its normal state, up to the Little River. There the base of the Georgetown limestone becomes more marly, until north of the Brazos River it is represented by dark-blue, calcareous, bituminous, laminated clays, together with beds of impure limestone. These beds have been called the *Kiamitia clays.* South of the Brazos River their thickness does not exceed 15 feet, but farther north it increases to about 150 feet. The clays extend north to the Red River. A calcareous rock of the Georgetown beds, on top of these clays, has been called *Fort Worth limestone.*

From the Brazos River to the north the base of the Georgetown formation has been subdivided still more. There begins to appear above the Kiamitia clay a series of white, chalky limestones and blue marls, weathering yellowish-white. These beds, which are hardly distinguishable near the Brazos River, obtain a great importance in the northern part of Texas, and are especially well developed in the Red River section in Grayson, Cooke, Denton, Tarrant, and Johnson counties. They are called *Duck Creek formation.* Their thickness is about 194 feet at Denison and only 40 feet near Fort Worth.

The Kiamitia clay and the Duck Creek formation together have been designated as *Preston beds.*

That part of the Georgetown formation which lies on top of either the Kiamitia clay or the Duck Creek formation, and which, north of the Brazos River, has been called *Fort Worth limestone,* is composed of impure bluish limestones in layers of perhaps one foot thick, alternating with layers of bluish marly clay. Both kinds of rock, when weathered, become white or yellowish in color. This limestone is very well developed in the railway cuts north of the Union Station of Fort Worth. Its thickness is generally 100 feet. It extends from the Little River in a fairly broad belt nearly due north up to the Red River.

Not only the lower part of the Georgetown formation splits up into different subdivisions north of the Brazos. but also the upper beds. North of the Trinity River we find above the Fort Worth limestone a mass of light-colored calcareous marls, some brownish marls and flag-like layers of shell agglomerate. This series has been called the *Denton subgroup.* In the north near the Red River, this group is about 35 feet thick, but thins toward the south, where it cannot be separated from the Georgetown limestone. On top of these beds we find beds of bluish shale, interstratified with sandy layers, about 40 feet thick, and designated as the *Weno formation.* Above this lie 5 feet of light yellow crumbling limestone, called the *Quarry bed,* and above it about 40 feet of friable arenaceous clay with thin layers of sandstone. This series is called the *Pawpaw beds.* The Weno formation, Quarry limestone, and Pawpaw beds together have been called the *Weno subgroup.* This subgroup is well developed only in the Red River region. Toward the south, the Quarry limestone disappears in Denton County, the sandy character changes into a calcareous one, so that the beds become more and more similar to the Fort Worth limestone. The subgroup is still to be recognized at Fort Worth, but farther south merges entirely into the Fort Worth limestone.

Del Rio Clay. The Del Rio clay, also called Arietina clay, overlies the Georgetown beds, in the south. It is a peculiar greenish-blue, laminated clay, in places gypsiferous, weathering dull yellow or brownish, containing thin slabs of shell breccia, and near the top thin layers of arenaceous limestone. Concretions of pyrite are found in the clay and explain the formation of the gypsum mentioned above. The Del Rio varies much in thickness; near the Rio Grande it has been found that in some places it is only 30 feet thick, while in others it is 80 to 90 feet, and near Del Rio it reaches its maximum with nearly 200 feet. Near Austin we find a thickness of about 80 feet; in McLennan County, only 60 feet. It exists, partly as a belt, partly in isolated patches, in all the country from the Rio Grande to the Brazos River. Farther north it changes in character, and grades imperceptibly into brecciated, white, marly limestone, weathering deep yellow; and yellow marls alternating with limestone. This series has been called the *Pottsboro subgroup*, and has been subdivided into the lower *Mainstreet limestone,* so-called on account of its exposure in Main Street in Denison; and the upper *Grayson marls.* Mainstreet limestone is a brecciated white limestone weathering deep yellow, thicker-bedded at the base than at the top and containing some sandy marly layers. Its thickness varies between 15 and 25 feet in the region where it is best developed in Grayson County. It is found also in Cooke, Denton and Tarrant counties. The Grayson marls are light-colored marls, with a great number of calcareous concretions and much pyrite, yellow and blue clay. Its thickness is about 50 feet, and its distribution is about the same as that of the Mainstreet limestone.

Buda Limestone. The Buda limestone, also designated as Shoal Creek limestone, and Vola limestone, is a whitish or yellowish limestone, with blotches of pale pink. The rock is generally not very hard, is thin-bedded in the lower part, and is quite heavy-bedded above. The Buda limestone is exposed along a line from the Rio Grande up to the Brazos

River, following generally the Balcones fault line. It constitutes also a great part of the surface of the Edwards Plateau and of its continuation across the Pecos River. In its southern exposure it has an average thickness of 80 feet, at Austin it is 50 feet, and from there it begins to thin out rapidly toward the north, showing a thickness of 20 feet at Round Rock, of 10 feet at San Gabriel River, of 3 to 5 feet at Moody, and of one-half foot at the Brazos River.

It has not been proved conclusively by which formation the Buda limestone is represented to the north of the Brazos River. R. T. Hill thinks it should be correlated with the Grayson marls of the Pottsboro subgroup, but he is not able to give any real proof for this. There are good reasons for believing that the Buda limestone may be represented in the north by at least part of the Woodbine formation. According to the fossil fauna in this latter formation, its age cannot be far from that of the Buda limestone. The Woodbine formation is generally included in the upper Cretaceous, but as long as the Washita division is included in the Comanchean, the same should be done with at least part of the Woodbine sands.

Trans-Pecos Region

Lowest Comanchean

The existence of the Lowest Comanchean in the Trans-Pecos Region is known only from two fossils figured by F. W. Cragin, and considered by him as Jurassic. They occur in his so-called *Theta subdivision,* one and one-half miles east of Malone railway station. The Theta subdivision, which in its greater part belongs to the Upper Jurassic, consists chiefly of gray and brown sandstone, with occasional courses of bluish-black limestone and some clay. It is impossible to give any more data on the part of the Texas section which must belong to the lowest Comanchean. It is probable, however, that these strata exist also west of the Malone Hills.

Trinity Division

This division has been recognized in many localities in the Trans-Pecos Region, but it has not always been possible to establish the subdivisions recognized in Central Texas.

Lower Trinity beds have been found in the region of Malone and in the mountains east of that station. The lowest bed, called *Mountain bed,* by Taff, consists of coarse, vari-colored sandstone and siliceous limestones. The exact thickness of this formation cannot be determined on account of folding and faulting. It occurs in the western portion of the Quitman Mountains. Above this lies the *Quitman bed,* composed of sandstones, clays and thin beds of limestone, about 330 feet thick. This has almost the same distribution as the Mountain bed.

To the lower Trinity beds may belong also the lower part of Udden's *Presidio beds,* at Shafter, Presidio County. These are composed of sand, conglomerates, gravels, clay, sandstones and sandy limestones. The Presidio beds are about 440 feet thick. That part of them which probably belongs to the lower Trinity division is about 250 feet thick.

In many places we find above the Paleozoic rocks conglomeratic and sandy masses which form the base of the Comanchean. Several of these may represent the lower Trinity division, but of others we know that they belong to the upper Trinity (Glenrose) or even to the Fredericksburg and perhaps Washita divisions, as will be shown farther on.

Upper Trinity beds are known in many places in this region. In the Quitman Mountains and the Bluff Mesa, east of it, they are represented by heavy limestone, sandstone, clays, and thin-bedded to massive limestone (Taff's *Bluff bed*). This whole series is about 650 feet thick.

At Shafter, Presidio County, the Upper Trinity division is represented by the upper 150 feet of Udden's *Presidio beds* and by the lower 500 feet of his *Shafter beds.* These consist of alternating ledges of limestone, hard marls, clays, lenticular masses of yellow and brown sandstones. The total thickness of these beds is about 700 feet, of which the lower part represents the upper Trinity division.

The upper part of the Trinity division exists also in the region south of Marathon. At Persimmon Gap in the Santiago Range, the lowest Cretaceous consists of 100 feet of shaly calcareous strata, 20 feet of conglomerate and 200 to 300 feet of limestone. These latter rocks represent certainly the upper Trinity division.

The Fredericksburg Division

This division is generally very well developed in the Trans-Pecos Region. In the Quitman Mountains it consists of quartzitic sandstones, massive limestone (350 feet), argillaceous limestone, shales, heavy-bedded limestone and dark clays with brownish calcareous bands. The whole series is about 1,500 feet thick.

A similar development exists in the Finlay Mountains. There it has been subdivided by G. B. Richardson into three divisions. The lowermost is the *Campa Grande formation,* which consists of a 25-foot limestone conglomerate at the base and 350 feet of gray, generally massive limestone. This contains locally thin beds grading into shales. This formation rests unconformably on the Paleozoic Hueco limestone. It occurs mainly in the Finlay Mountains. It is covered by the *Cox formation,* which is composed of massive soft, brownish sandstone, some intercalated gray limestone and near the base, a red-drab, shaly rock. The entire formation is about 600 feet thick, of which probably 500 feet are sandstones. This formation occurs in the Finlay Mountains, in the Diablo Plateau, Cox Mountains and several other places in the same region. The highest part of the Fredericksburg division is composed of the *Finlay formation.* It consists almost entirely of massive gray limestone and shows locally thin beds of brown sandstone. The entire thickness is at least 300 feet. The formation makes the outer rim of the Finlay Mountains as well as a large flat area north of these and it is also exposed in the Sierra Blanca region.

The Fredericksburg division has thus, in this region, a thickness of at least 1,275 feet.

In the Shafter district of Presidio County, the Fredericksburg division seems to decrease much in thickness. Its lower part consists of about 200 feet of an alternation of limestones and marls, perhaps also sandstones, which form the upper part of the *Shafter beds.* The upper part is composed of a massive, white, heavy-bedded limestone, about 350 to 400 feet thick. Seams of flat rocks of gray flint occur about 100 feet above the base. This mass represents, according to Udden, probably not only the Edwards limestone, but also the Georgetown formation.

Between Alpine and Marathon we find the Fredericksburg division in the Altuda Mountain, covering the Permian. At the base we find occasionally very little yellow sandstone or only a few quartz pebbles. Above these occur about 100 feet of moderately heavy ledges of gray limestone, which is covered by 40 feet of heavier ledges; then follow 60 feet of softer and thinner ledges of limestone. The top is formed by several hundred feet of heavy-bedded white limestone. The entire series is at least 800 feet thick and represents the greater part of the Fredericksburg division.

This division appears also in the Cienega Mountains. There it consists of 300 feet of somewhat impure limestone with shaly seams overlain by several hundred feet of massive limestone. Below this series we find 25 feet of conglomeratic sandstones and 150 feet of shales, shaly limestone and sandstone, the age of which is unknown.

In the great escarpment of the Mesa de Anguila in the angle formed by the Terlingua Creek and the Rio Grande, we find 700 feet of massive limestone overlain by 200 feet of impure limestone with marly layers. The top is formed by 600 feet of heavy-bedded white limestone. This mass contains certainly the Fredericksburg division. Similar limestones are found in other localities of the region, for example, at Christmas Mountains where their thickness is about 1,000 feet, and at the Carmen Range, where the limestone attains a thickness of more than 2,000 feet; but this mass possibly contains also the whole Washita division.

North of Marathon in the Glass Mountains the Fredericksburg division seems to cover unconformably the Permian. There the Comanchean is composed of 70 feet of conglomerate of limestone, about 20 feet of interbedded yellow sandstone and conglomerate, 80 feet of heavy cross-bedded sandstone and conglomerate, and about 100 feet of light gray limestone, heavy-bedded below, thin-bedded above.

Farther north near the station of Kent, on the Texas and Pacific railroad, the Fredericksburg division seems to be represented by 45 feet of limestone, and about 20 feet of sand at the base.

Washita Division

This division is very well represented in numerous localities of the Trans-Pecos Region but only in a few places has a correlation with the east Texas subdivision been possible.

At Cerro de Muleros, in New Mexico, and extending into Texas, opposite El Paso, this part of the Comanchean has been described by Bose. The base of the Comanchean here consists of 80 to 90 feet of light gray, quite thick-bedded limestone which possibly represents the highest part of the Fredericksburg division. On top of this Böse found gray to yellowish marls, sometimes laminated, with thin layers of dark blue limestone, brown sandy limestones, sandstones, black and gray shales having a thickness of about 200 to 250 feet. These represent, probably, the Preston beds of north-central Texas. Above these lie about 150 feet of gray to bluish marls which turn whitish by weathering. They represent the Fort Worth limestone and Denton subgroup. They are covered by about 70 feet of gray and brown marls with interbedded thin layers of brown sandstone and beds of limestone. They represent the Weno subgroup. On top of these we find a heavy-bedded red, white and yellow coarse sandstone, 70 to 300 feet thick, which may be correlated with the Pottsboro subgroup and the Del Rio clays. Above it we find about 50 feet of yellowish marls, interbedded with marly limestones and calcareous nodules, and on top of it a hard, white-gray limestone, weathering white, heavy-bedded and about 50 feet in thickness. This rock certainly represents the Buda limestone. These rocks are covered by about 800 to 900 feet of yellowish white quartzitic sandstone, the age of which is unknown. It may represent the upper part of the Buda limestone, the Woodbine sands, or the lowest part of the Eagle Ford shales.

The Washita division has been found in Sierra Blanca, Black Mountain and the Cornudas. In the latter locality it lies directly on the Paleozoic Hueco limestone.

At the southern end of the Quitman Mountains near the Rio Grande we find the Washita division represented from below to above by (1) 300 feet of argillaceous, light-gray limestone, interstratified with dark clay shales; (2) 300 feet of heavy-bedded limestone; (3) 70 feet of heavy-bedded and of argillaceous nodular limestone. These beds represent certainly the whole Georgetown formation. Above them we find 300 feet of argillaceous limestone with some bands of clay and sandstone which represent the Del Rio clay.

In Presidio County near Shafter, the Georgetown is probably represented by a massive white limestone not to be separated from the Edwards limestone. Above this limestone lie 80 feet of clay with occasional thin layers of limestone, which probably correspond to the Del Rio clay. Above it is gray, heavy-bedded limestone, some 70 feet thick, which may represent the Buda limestone.

To the south of the Chisos Mountains, the Washita division has been observed in the Mariscal Mountain. There the whole Fredericksburg and Washita divisions seem to be developed in the form of limestone. The lower subdivision belongs to the Edwards limestone; higher up the limestone is softer and belongs to the Georgetown formation. About 50 feet of a very compact limestone resting upon it has to be considered as Buda limestone. West of the Chisos, in the region of Terlingua, the Buda and the Del Rio are both well developed; the latter as a soft green clay, 80 feet thick, the former as a heavy-bedded limestone.

UPPER CRETACEOUS

The Upper Cretaceous of Texas includes, from below upward, the Woodbine formation, Eagle Ford shales, Austin chalk, Taylor marl, Navarro beds and Escondido beds. We have already said that the Woodbine sands are probably in part the representative of the Buda limestone, so that in reality they should be discussed in the chapter on the Comanchean; but as they are generally considered Upper Cretaceous, we shall describe them with this series. Together the formation of this series known in the State approximates a thickness of 3,000 feet. It outcrops in a belt from 30 to 75 miles wide, extending from Red River County in the northeast to Grayson County, then south to Bexar County, and from there to Kinney County on the Rio Grande. Southward and eastward from this belt it dips under the Tertiary sediments and as the coast is approached is encountered in borings at increasing depths. On the south part of the Edwards Plateau from Devil's River westward to the Pecos River, and some distance beyond, the lowermost part of the Upper Cretaceous remains in places as a thin cover on the Comanchean limestone. In the mountainous regions in west Texas it is frequently preserved in places where the ground has been folded downward or where large areas have settled. We will here describe the series separately for the two principal areas in which it occurs, in the central and in the western part of the State.

Central and East Texas

Woodbine Formation

The Woodbine formation, also called Timber Creek group and Lower Cross Timbers formation, is made up largely of ferruginous, argillaceous sands of brown and red color, accompanied by bituminous laminated layers. Its thickness is 500 to 600 feet near the Red River, but it decreases rapidly toward the south. At Fort Worth it is 300 feet; at Cleburne, 200 feet; northwest of Hillsboro, 95 feet; north of Waco, 45 feet. It seems to disappear at the Brazos River. The Woodbine formation has been subdivided into two subgroups, the *Dexter sands* and the *Lewisville beds*. The Dexter sands which form the base of the Woodbine formation and which by J. A. Taff have been further subdivided into *Basal clays* and *Dexter sands*, consist of a brown and yellow ferruginous sandstone with siliceous ironstone. They are best developed in Tarrant, Denton and Cooke counties. In the northern part they are about 300 feet thick. The Lewisville beds are composed of laminated lignitic sands and sandy clays interstratified with brown sands, ferruginous reddish-brown sandstone, shell sandstone and argillaceous shelly sandstone with lense-like, calcareous concretions and laminated, argillaceous sandstones at the top. Their thickness is about 50 to 100 feet.

According to R. T. Hill an unconformity may possibly exist between the Grayson beds and Woodbine sands, but it has not been proven anywhere. According to F. L. Whitney, near Austin a slight unconformity exists between the Buda limestone and the Eagle Ford shales, but this disappears a short distance north of Austin.

Eagle Ford Formation

The character of this formation varies considerably. In the north part of the State it is composed of blue and black laminated bituminous clays, with large septaria, sands, clays, shales, and thin layers of brown sandstone. The upper sandy part has been called *Blossom sand* by C. H. Gordon. Toward the south the formation becomes more calcareous and in part more sandy. Near Waco it consists of bluish and gray shales and arenaceous laminated shales. Farther south thin-bedded and laminated limestones begin to alternate with the shales until at the Rio Grande the formation consists of a thin-bedded, cream-colored limestone, alternating with laminated marly shale and clay, especially in the lower part. This difference in their physical character caused E. T. Dumble to give the local name of *Val Verde flags* to the Eagle Ford formation along the Rio Grande.

The thickness of this formation varies. In the north, near the Red River, it is estimated at 600 feet; in the Dallas region at from 480 to 500 feet; in the Waco district it measures 200 feet; near Austin, 50 feet; on the Nueces River, 200 feet; near Brackett, 250 feet; on the Rio Grande, 250 feet. It is still thicker toward the west.

The Eagle Ford formation forms an east and west broad belt south of the Red River, beginning in the east, north of Clarksville, and ending near Ravenna, in the west. There some structures move the formation farther to the south where it forms another east and west belt beginning in the east near Bagby, and ending east of Whitesboro, where it turns into a north-south belt. This passes near Dallas, Hillsboro, west of Waco, Georgetown, and Austin; takes a more southwesterly direction, passing through New Braunfels and San Antonio; turns nearly due west, continuing through Uvalde and north of Spofford Junction; and finally crosses the Rio Grande between Jimenez and Del Rio.

Austin Chalk

This formation consists of a fairly thick-bedded, impure chalk, interstratified with marly beds. The rocks are entirely white on the surface, but their subterranean parts have a bluish color which they lose when dried in the air. They contain, frequently, nodules of pyrite. In the upper part of the Austin chalk marly and shaly beds begin to predominate. These alternate with thick layers of chalk. The highest part of the formation consists entirely of bluish-yellowish marls with thin beds of limestone.

In the Red River region Gordon has shown that the Austin chalk is represented by two beds: The *Brownstown marl* below and the *Anona chalk* above, names which had been introduced by R. T. Hill but which were thought to belong to a much higher horizon. The Brownstown marls are light-blue, calcareous and sandy clay or marl, about 300 feet thick. The Anona chalk consists of bluish and creamy white chalk similar to the corresponding beds of the Austin chalk. It is about 100 feet thick.

At the Rio Grande, between Eagle Pass and Del Rio, the Austin chalk is much less chalky than farther to the north. Especially in its lower part, we find hard white limestone predominating. On account of this special character, Dumble gave these beds the local name of *Pinto limestone.* The thickness of the Austin chalk is generally between 400 and 750 feet. The formation overlies the Eagle Ford shales. In the north, it lies to the south of them; from Sherman, Grayson County, southward, it is situated to the east of the other formation; and from San Antonio westward, again to the south.

Taylor Formation

The Austin chalk is covered by a series of laminated calcareous marls, originally bluish-black, but weathering into a whitish-yellow clay. In the northernmost part of the State, the Red River region, the beds above the Austin chalk have received different names, but it has not been possible to distinguish the Navarro beds from the Taylor beds. These latter are probably represented by the *Marlbrook marls* (which have also been called *Kickapoo marls*). These consist of chalky, glauconitic, blue marls and in places, impure chalk. Their thickness varies between 50 and 750 feet.

The Taylor formation, also called *Exogyra ponderosa formation,* changes its character considerably in the south near the Rio Grande and in the Uvalde region. In the vicinity of the Rio Grande, between Eagle Pass and Jimenez, the place of the Taylor marl is occupied by a dark gray or greenish-gray clay weathering yellow, which often carries crystals and thin seams of gypsum. Crystals of barite have also been found. Dumble has called these deposits the *Upson clays.* These clays outcrop over all the region to the south, southwest and southeast of Spofford, and cross the Rio Grande into Mexico. From Spofford to the east they form a narrow belt under the north cliff of the Anacacho Mountains. Here the character of the Taylor formation changes again. The Upson clays become thin and are in part glauconitic and sandy, while part of their place is occupied by a series of yellow limestones and calcareous sandstones in strong ledges, some of them chalky, but most of them marly. This series has been called the *Anacacho limestone.* It represents in part the Taylor marls, but probably also some of the Navarro formation which covers them in other parts.

The thickness of the Taylor marls in the northern part of the State has not been measured. In the central region they seem to be about 600 to 650 feet thick. At the Rio Grande the Upson clay has a thickness of about 500 feet, while the Anacacho limestone is about 400 feet thick.

The Taylor marls extend in a broad belt from Grayson and Fannin counties in a north-northeast to south-southwest direction to Williamson County. There the belt narrows, but continues farther southwest, passing near San Antonio, then turning nearly due west toward the Rio Grande.

Navarro Formation

The Taylor marls grade up into a series of glauconitic marls with beds of limestone, black clays and sandstone. These beds represent the highest Cretaceous existant in central Texas. They have been called also the *Upper Arenaceous series,* the *Glauconitic division,* the *Webberville beds,* and the *Bexar formation.*

In the region adjacent to the Red River, the Navarro formation has been subdivided in ascending order into the *Nacatosh sand* and the *Arkadelphia clay.* The former consists of glauconitic sands with thin ledges of calcareous sandstones, showing a thickness of 60 to 160 feet. The Arkadelphia is a dark laminated clay, 200 to 500 feet thick. It has not been possible to determine whether or not the limit between the Nacatosh sand and the Marlbrook marls corresponds exactly to that between the Navarro and Taylor marls. These subdivisions are more or less of a local importance. The character of these glauconitic sandy and marly rocks changes so rapidly that local names have been given to the formation or parts of it in different regions. A series of brown sandy marls with an occasional band of hard calcareous sandstone in its upper portion and with fine pebbles of jasper and quartz imbedded in the higher part of the clay, has been called *Corsicana beds;* above these exists a bed of yellow clay with concretionary nodules, and this has received the name of *Kemp clay beds.* These two formations occur between Sulphur River in Delta County and the Brazos River. The upper one of these beds, however, has a somewhat uncertain position. It is not quite clear whether this really belongs to the Cretaceous, or to the Tertiary.

Near Austin the Navarro formation has been called *Webberville beds.* These consist of glauconitic marls with beds of impure limestone in their higher portion, grading upward into bituminous, black, arenaceous clays.

Toward the Rio Grande, the character of the formation changes in a great measure. We have already seen that in Uvalde County the Taylor marls are replaced by the Anacacho limestone, the upper part (60 feet) of which probably belongs to the Navarro formation. The upper layers consist of a brown ferruginous sandstone occurring in ledges or slabs, clays and marls with some ledges of sandstone, limestone and shell beds. These beds have been called by T. W. Vaughan the *Pulliam formation.* Their thickness is about 100 to 200 feet at the Nueces River. Farther west, south of the west end of Anacacho Mountains, the formation increases to about 500 feet.

Farther toward the Rio Grande the formation undergoes another change. It splits up into three distinct subdivisions. These have been called by E. T. Dumble, beginning with the lowest, the *San Miguel beds,* the *Coal series,* and the *Escondido beds.* All these together are known under the name of the *Eagle Pass formation.* The San Miguel beds consist of a number of gray and brown quartzitic and calcareous sandstones alternating with clay and shales, with a thickness of not much more than 400 feet. These rocks represent the highest part of the Anacacho limestone and the base of the Navarro formation. These beds are covered by the Coal series, which consists of clays, dark shales, and white and yellow sandstones that contain seams of coal and fireclay. One of the coal seams is 6 feet thick. The series has a total thickness of about 350 feet. Above it we find the Escondido beds. These are composed of white, yellow to brown sands, sandstones and conglomerates interbedded with greenish-blue clays and rare layers of gray limestone. The clays constitute the greater part of these beds and frequently contain calcareous nodules. The whole series is at least 600 feet thick. The Escondido beds probably are somewhat younger than the Navarro beds in central Texas, so that only the San Miguel beds and the Coal series would really correspond to the Navarro beds.

In most parts of the State it has not been possible to estimate the thickness of the Navarro beds because these grade imperceptibly into the underlying Taylor marls, but it seems that in many places they are 600 to 800 feet thick.

The Navarro formation forms a broad belt beginning in Red River, Delta and Hunt counties, tapering toward the south-southwest and passing the region of Greenville, Terrell, Kaufman, Corsicana, Ogden, Burlington, Thorndale, Webberville, Mendoza, Seguin, and San Antonio; from whence it goes toward the west to Eagle Pass and crosses the Rio Grande into Mexico.

Trans-Pecos Region

The Upper Cretaceous is well represented especially in the southern portion of the Trans-Pecos country, although the character of the rocks is in some places different from that of the rocks of east and central Texas.

Eagle Ford Shales

The horizon of the Eagle Ford shale exists on the Cerro Muleros near El Paso, but it is found entirely on the Mexican side. It is principally composed of dark brown sandstone and shales with sandy limestones. A little farther east we find it in the Quitman Mountains occurring as a great thickness of dark brown shale with occasional bands of impure limestone. The same rock is found in the Eagle Mountains about 760 feet thick.

A very similar rock of certainly the same age is known in several places on the plains between the Glass Mountains and the Davis Mountains.

West of the Devil's River and in the Big Bend country the Eagle Ford shales have a somewhat different character. There they consist of a limestone in flaggy beds, which contain a slight admixture of fine siliceous sand and clay. At certain horizons they have a chalky texture. The color varies between gray, yellowish-white, and dark, almost black. These rocks have been called *Boquillas flags* by Udden. Their thickness is rather uniformly about 600 feet in the Big Bend country. This rock extends all along the western flank of the Carmen range, around the Mariscal and the Christmas mountains and over a large area southwest from Paso Del Norte. West of the Terlingua Creek it extends from Cuesta Blanca to the Reed plateau, and south of Terlingua it extends still farther west.

Austin Chalk

The Austin chalk exists in the vicinity of the San Carlos coal field and in the Van Horn Creek valley north from this place. Typical chalk and soft gray marls are both present. In the Chisos country, in the Big Bend of the Rio Grande, the Austin chalk is represented by a white, soft or indurated, stratified chalk, which is some 250 to 300 feet thick and grades, in places, from almost black up to an impure gray marl and hard rock. It has not been possible to determine the exact thickness of the chalky beds because they grade imperceptibly into a marl which certainly in part represents the Taylor marls. This whole series was therefore called the *Terlingua beds*, by Udden, and measures about 1,250 feet. These rocks are found east of the Chisos Mine, in Cottonwood Creek, around Mariscal Mountain, near Talley Mountain, in the valley along the west side of Carmen and at other places near the Rio Grande and along Terlingua Creek.

Austin chalk entirely similar to the east Texas rock of this age has been found north and northwest of the Glass Mountains, in the Davis Mountains, and in the Barilla Mountains.

Taylor Marls

The Taylor marls are well represented in the San Carlos coal field in the Tierra Vieja Mountains of Presidio County. They consist of gray and yellow clays and brown or yellowish sandstones. The thickness of these rocks is at least 400 feet. They have been called *Vieja series* and *San Carlos beds,* by Vaughan.

The Taylor marls seem to be very similar to these rocks in the Terlingua country. They consist of clays, in the uppermost part of which there are some thin layers of concretionary limestone and calcareous sandstones. As already stated, it has not yet been possible to separate these rocks from the underlying Austin chalk, and Udden includes both of them in his Terlingua beds, which have a thickness of about 1,250 feet.

Taylor marls are also found in the Davis Mountains and in the Barilla Mountains.

Navarro Formation

The highest Upper Cretaceous has been found only in the region of the Big Bend of the Rio Grande. It is possible that a series of yellow and purplish clays and yellow sandstones which contain the coal seams of the San Carlos coal field in Presidio County represent the lower part of the Navarro beds, although there is no paleontological proof of this. These beds, which are about 1,000 feet thick, certainly rest on the Taylor marls and are younger than these marls.

Like these are the rocks of a series above the Taylor marls in the Chisos country. These beds have been subdivided by Udden from below upward into the *Rattlesnake beds*, the *Tornillo beds*, and the *Chisos beds*.

The *Rattlesnake beds* are composed of sandstones, muddy and peaty clays and silts, some thin layers of limestone, thin beds of gravel, and often layers of volcanic tuff. The thickness of this zone is about 600 feet. The Rattlesnake beds contain at least one coal seam. These beds are exposed in an irregular belt from one to several miles broad, encircling the Chisos Mountains.

The *Tornillo clays* consist of gray, dull olive green, dull blue, dull and bright red, dull and bright yellow, purple, brown, sometimes black and white clays, with occasional thin lentils of sandstone. These clays are about 600 to 700 feet thick. They form a circular belt around the Chisos Mountains, inside of one of the Rattlesnake beds.

The *Chisos beds* are composed of chocolate gray to brown clay in layers, grayish blue to white tuffaceous sediments, sandstone and occasional ledges of conglomerate. The whole series is stratified in thin and well-defined ledges and layers. This series seems to have a thickness of probably 2,000 feet. The Chisos beds appear almost everywhere in the valley in the east half of the Chisos Mountains and extend in a narrow cresentic belt around their west side.

The last two formations have not yet yielded any fossils so that their exact age is not known. It is likely that the Chisos beds may be later than the Cretaceous.

CENOZOIC

TERTIARY

From the outcrop of the Cretaceous, the shoreward coastal plain is underlain by what is known as the Tertiary, which outcrops in belts extending in a general northeast-southwest direction. These sediments overlie the Cretaceous. Successively younger formations form the surface, as the shore line of the Gulf of Mexico is approached. The Tertiary area begins near the northeast corner of the State on the east, and on the southwestern or Rio Grande border it extends west to four miles above the Webb-Maverick county line. The country between the Brazos and Colorado rivers marks a more or less distinct region of division between the northeastern and southwestern earlier Tertiary areas. East of this line the deposits belong to the Mississippi embayment, and west of it they belong to the Rio Grande embayment. The nature of the deposits is somewhat different in the two regions, more formations of middle Eocene being recognized in the southwest than in the northeast. The Tertiary formations called the Jackson and the Corrigan are known only in the east, and the Fayette and Frio are known only in the west. The two embayments are not well defined after the close of the Oligocene. The Tertiary sediments consist mostly of slightly indurated sands and clays, with some few limestones and some beds of lignite.

	Eastern Gulf Coastal Plain		Western Gulf Coastal Plain		Northwest Texas
PLIOCENE	Fleming (in part)		Lagarto Lapara		Blanco
MIOCENE	Fleming (in part)		Oakville		Clarendon Panhandle
OLIGOCENE (?)	Corrigan or Catahoula				
EOCENE	Jackson		Frio		
	Claiborne	Yegua or Cockfield	Fayette		
		Cook Mountain	Yegua		
		Mount Selman	Cook Mountain		
		Queen City-Carrizo	Mount Selman		
	Wilcox		Midway	Myrick	
	Midway		Carrizo		
			Wilcox		

GULF COASTAL PLAIN

Eocene

The oldest period of the Tertiary is called the Eocene. In the Gulf Coastal Plain it is subdivided into the following four stages, given in order from the oldest and lowest: Midway (also known as the Basal or Wills Point), Wilcox, Claiborne, and Jackson.

Midway (also known as the Basal or Wills Point)

The strata of this stage do not outcrop on the Red River along the eastern border of the State, but are known from borings to be predominantly clayey with glauconite and sand in thin layers and also thin beds of rock, probably in part sandstone and in part limestone. East of the Colorado River, the Midway consists at the base of bluish, micaceous, laminated clays or clayey sands with occasional light yellowish, fossiliferous, nodular limestone layers of marine origin. Above are sandy ledges, succeeded by black gypsiferous clays, with small limestone concretions containing in places many fragments of shells. In southwest Texas and on the Rio Grande, the lower part is made up of twelve or thirteen feet of gray fossiliferous limestone interbedded with thinner layers of greenish-gray sand at the base, and the upper 150 to 200 feet is composed of massive, dark gray, slightly indurated, more or less argillaceous and glauconitic sand, with harder ledges at intervals of 5 to 15 feet, and subordinate layers of shaly clay that contain concretions of iron carbonate in the upper 50 feet. The Midway lies unconformably on the upper Cretaceous and has a thickness of 200 to 400 feet, perhaps averaging 260 feet. It outcrops in a narrow belt in Hopkins, Hunt, Rains, Van Zandt, Kaufman, Henderson, Navarro, Freestone, Falls, Robertson, Bastrop, Caldwell, Guadalupe, Bexar, Medina, Uvalde, Zavalla, and Maverick counties. In the western area of its outcrop the Midway is included in the lower part of the Myrick formation. In Caldwell and Bastrop counties it has been called the *Lytton formation.*

Wilcox (also known as the Lignitic, the Sabine, the Sabine River, and the Timber Belt Formation)

The Wilcox is marine only in the region of the Sabine River between Pendleton and Sabinetown. At Pendleton the strata are of lower Wilcox age, belonging to the Nanafalia substage of Alabama. At Sabinetown the beds are of upper Wilcox age, or the Woods Bluff substage of Alabama. The marine Wilcox is mainly dark-colored, sandy, laminated clays, with glauconite, large concretions of iron carbonate, and lime nodules.

The non-marine Wilcox of east Texas is composed of sands, sandstones and clays, often laminated, and beds of lignite, the whole being from 800 to 1,200 feet in thickness.

In the northeastern area and the vicinity of the Rio Grande, the Wilcox overlaps and conceals the Midway, and rests directly upon the Upper Cretaceous.

In the western part of the Gulf Coastal Plain, the Wilcox is composed for the most part of siliceous sands, and also contains glauconitic sands, lime, clays of various colors, and beds of lignite. The Wilcox occurring in eastern Maverick county, eastern and northern Zavalla county, southeastern Uvalde County and southern Medina County forms the middle portion of the Myrick formation. The lower 200 feet of the Myrick is composed of sediments belonging to the Midway. The upper portion, made up of yellow, non-calcareous and blue sands with interbedded blue shale belongs to the Carrizo formation (here classed as Claiborne). Between these there occur beds of the Wilcox with a total thickness of 800 feet, showing at the top yellow and blue shales with beds of lignite, brown sandstone and hard blue sandstone concretions underlain by coarsely crystalline, non-calcareous, quartzitic, white to yellow sands, which in turn overlie yellow and brown sandstones with beds of lignite and sandy shales.

Along the Rio Grande the Wilcox is composed of a lower series of blue and gray sandy shales, light gray sandstones and bluish carbonaceous sandy shale with sulphur which is overlain by a second series, comprising black, lignitic, sandy shales with gray carbonate of iron concretions, and lignite deposits. There is less lignite and more sand in the formation along the Rio Grande than elsewhere. The lignite is not so abundant southwest of the Colorado as it is in east Texas. The beds become thinner as the Rio Grande is approached, and along that river may not be more than 100 feet thick.

The Wilcox outcrops in Bowie, Cass, Marion, Harrison, Panola, Shelby, Titus, Morris, Camp, Upshur, Gregg, Rusk, Nacogdoches, San Augustine, Sabine, Franklin, Hopkins, Rains, Wood, Smith, Van Zandt, Henderson, Cherokee, Anderson, Navarro, Freestone, Leon, Limestone, Falls, Robertson, Milam, Burleson, Lee, Bastrop, Caldwell, Guadalupe, Wilson, Bexar, Atascosa, Medina, Dimmit, Frio, and Webb counties. It has a broader area of outcrop in northeast Texas than elsewhere.

Claiborne Group

The Claiborne of Texas is composed of the following formations, named in order from the oldest to the youngest: Queen City-Carrizo, Mount Selman, Cook Mountain, Yegua, Fayette and Frio. The youngest two do not outcrop east of the Brazos-Colorado divide.

Queen City-Carrizo

The Queen City-Carrizo is by some geologists classed with the Wilcox. In east Texas the formation, known as the Queen City, is made up of laminated or thinly stratified white or red sands and sandy clays, 50 to 200 feet in thickness. In west Texas it is known as the *Carrizo* and there it consists of sandstones of varying color, texture, and thickness. The prevailing color is grayish-yellow, and this weathers to light brown, some of the beds showing white upon freshly broken surfaces. The beds range from fairly hard sandstone, lying in beds of two to four feet or more in thickness, to thin, slabby, fairly soft, and almost shaly structure. The thickness is at least 150 feet.

In the Rio Grande country the Carrizo in places overlaps the Wilcox and Midway, and locally rests directly upon the Upper Cretaceous. Vaughan regards the Carrizo as the lower part of the Wilcox.

Mount Selman

The Mount Selman in east Texas is composed of dark green and brown sands with thin beds of iron ore, lenses of lignite and clay, and beds and concretions of limonite. The workable iron ore, which is limonite, is always at or near the surface. The formation is at least in part of marine origin and has a thickness of about 350 feet. In the western region there are ferruginous sands and sandstones or altered glauconite with many rounded calcareous sandstone concretions, carrying marine fossils in places, and beds of clay and shale. The thickness is estimated at from 225 to 475 feet.

Cook Mountain

The Cook Mountain of east Texas has greensand, greensand marls, and iron ore all highly fossiliferous and of marine origin. It also contains lignites, lignitic clays and sands not of purely marine origin. The estimated thickness is 400 feet. The glauconitic sands and marls are the predominant strata in east Texas. These weather into red soils and form the so-called red lands. In the western region are fossiliferous, glauconitic marls with interbedded, ferruginous, glauconitic sands, sandstones and large concretions of fossiliferous, sandy limestone, weathering into red soils, with an estimated thickness of 540 feet.

Along the Rio Grande the Mount Selman and Cook Mountain formations are composed below of greenish clays and lignitic sands with palmetto and other plant remains, and some lignite. This is overlain by carbonaceous clays and sands that contain gypsum and particles of lignite. Uppermost is brown or buff sandstone. These formations are not so glauconitic along the Rio Grande as they are farther east.

The Mount Selman and Cook Mountain formations outcrop in Cass, Marion, Harrison, Upshur, Gregg, Panola, Rusk, Smith, Nacogdoches, San Augustine, Sabine, Cherokee, Houston, Anderson, Leon, Robertson, Madison, Brazos, Milam, Burleson, Lee, Bastrop, Caldwell, Fayette, Gonzales, Guadalupe, Wilson, Atascosa, LaSalle, Dimmit, Frio, Zavalla, and Webb counties.

Yegua

The Yegua formation is also called the *Cockfield*. In east Texas the Yegua consists of clay, sands and lignites, generally of not purely marine origin. It varies in thickness from 375 to 800 feet. Clay seems to predominate in the lower portion, most of the lignite seems to be in the middle, and sands prevail in the upper beds. The clays are laminated, thinly stratified, and massive in structure, and chocolate, dark blue, brown, and gray in color. The sands and sandy clays, which are sometimes micaceous, are brownish, drab, buff and gray. They range from laminated to massive, and are often cross-bedded. Laminated clays and sandy clays, sometimes leaf-bearing, frequently occur as lenses, pockets, and nodules in the sands, even when the latter are cross-bedded. Similarly, lenses of sand are found in the laminated, jointed clays. Fragmentary and crystalline gypsum is rather common in the Yegua strata.

In the western region the Yegua is composed of interbedded and interlaminated sands and clays with massive beds of sand, seams of plastic clay and kaolin, and heavy beds of lignite. In LaSalle and McMullen counties it has green and brown shales, beds of lignite, locally sands and sandstones, with oyster beds and beds of green shale in the lower portion. Here the formation has a total thickness of about 600 feet. Along the Rio Grande the Yegua has at its base interbedded brown sands, chocolate clays with green sand, and lenticular masses of red sandstone. This is overlain by buff and greenish sands, slightly calcareous, with occasional bands of limestone, and an abundance of gypsum and cannonball concretions. The upper portion is buff sandstone overlain by blue and green ferruginous clays having calcareous concretions. Above this part is yellow sandy clay. The Yegua along the Rio Grande is from 1,000 to 1,400 feet in thickness. The formation becomes more sandy and has more marine fossils along the Rio Grande than farther east. It carries very few marine fossils in east Texas, but they become more abundant between the Brazos and the Colorado, particularly west of the Guadalupe. The marine fossils are of lower Claiborne age.

The Yegua outcrops in Sabine, San Augustine, Nacogdoches, Angelina, Cherokee, Houston, Trinity, Madison, Leon, Walker, Grimes, Brazos, Burleson, Lee, Fayette, Gonzales, Wilson, Karnes, Atascosa, McMullen, LaSalle, Webb, and Zavalla counties.

Fayette

The Fayette is mainly sand and sandstones, with some beds of lignitic clays and sands with some lignite. The sandstones are sometimes indurated to a condition like that in quartzite. Silicified wood, often in the form of opal, is common, and there are also some beds of volcanic ash and siliceous sinter. The thickness is from 400 to 600 feet. The formation carries marine fossils west of the Guadalupe. Along the Rio Grande it consists of buff sandstone, some greenish sandy clay and lignitic clays. In these occur concretions, some lignite, opalized wood, and chalcedony. It is not known for certain whether the Fayette occurs east of the Brazos River. It may be there represented by a few outliers. It outcrops in Burleson, Fayette, Gonzales, Karnes, Live Oak, Atascosa, McMullen, LaSalle, Webb, Zapata, and Starr counties.

Frio

The Frio is a formation of yellow and dark clays which weather white and are accompanied by gypsum. It contains a few marine fossils. It thins to the northeast and is not found east of the Colorado and perhaps not east of the San Antonio River. In LaSalle and McMullen counties the Frio consists of greenish and pinkish red, compact, jointed clay, that has small lime nodules, and concretions of siliceous limestone. The lower part consists of beds of fossiliferous brown marl. The formation has a total thickness of about 660 feet. Along the Rio Grande it consists of gypseous clays with sands. The clays are gray and green in color. They often weather white and contain leaf impressions and ferruginous and calcareous concretions. The Frio outcrops in Karnes, Live Oak, McMullen, Duval, Webb, Zapata, and Starr counties.

No sediments of upper Claiborne are certainly known in Texas. Some, however, regard the Yegua as upper Claiborne and the Fayette and Frio as Jackson.

Jackson

The Jackson is found only in the region east of the Brazos-Colorado divide. The lower strata are calcareous clays and sands that contain nodules and bands of impure limestone, and carry abundant marine fossils. In the region east of the Neches the base of the Jackson consists of greenish clays and sandy clays with some sand and greensand. West of the Neches these beds are seemingly underlain or replaced by sandy carbonaceous shales and sands, with silicified logs, massive, rather fine-grained sandstones, and lignitic clays. These have been called the *Wellborn beds*. Both in the east and in the west the basal beds are overlain by grayish-brown sandy clays with seams of sulphur. These are succeeded upward by buff sandy clays that contain plant fragments, and gray-drab clay with gypsum and sulphur. Overlying these there is a series of lignitic or carbonaceous chocolate clays and sands, with which are interbedded light brown sandstones with a white porcelaneous cement, and coarse-grained gray sandstones which are sometimes highly indurated. Thin beds of lignite occur. The upper beds of the Jackson are light-greenish sands and carbonaceous sandy clays, capped by dark brown sandy carbonaceous shales that contain plant fragments, gypsum and sulphur seams.

The Jackson becomes more sandy and thicker toward the west. Marine fossils are found sparingly throughout the formation. There are at least two beds of volcanic ash in the upper portion. The Jackson has a thickness of from 400 to 500 feet and outcrops in Sabine, San Augustine, Angelina, Polk, Trinity, Houston, Walker, Grimes, and Brazos counties.

Oligocene (?)

Corrigan Formation (also known as Catahoula or Grand Gulf)

The Corrigan formation consists of coarse "rice" sand and sandstones at the base, overlain by finer sands and by yellowish-green clay and claystones with plant remains. The sand consists of coarse, polished, and frequently oblong grains resembling grains of polished rice. The clays and claystones carry pyritic nodules and streaks of lignite, and weather yellow to cream color. The sands are coarse to fine-grained and may be loosely consolidated, cemented with opaline or porcelaneous matter, or hardened to a dense grayish quartzite. There are local unconformities between the sands and clays. The sandstones often carry clay balls and are occasionally cross-bedded. Fossil palms are abundant and the fossil wood is often opalized. From the Trinity River westward sands are interbedded with calcareous clays in the upper part of the formation. The Corrigan is of non-marine origin.

The age of the Corrigan formation is not known. The lower sandstones are thought to belong to the Grand Gulf Oligocene, but the upper beds may be later than the Grand Gulf Oligocene. The Corrigan is known only in east Texas. Its thickness ranges from 250 to 600 feet. It outcrops in Newton, Jasper, Angelina, Tyler, Polk, Trinity, San Jacinto, Walker, Grimes, and Brazos counties.

Miocene and Pliocene

The deposits of the Miocene and Pliocene periods overlie the Eocene and Oligocene (?) gulfward from the outcrop of the Eocene. They have as yet been studied but little in detail. In their areas of outcrop they are nearly everywhere of non-marine origin, and carry fossils of land vertebrates. When they are encountered in deep drilling near the present Gulf shore they carry brackish water and marine fossils. The age of these deposits ranges from middle Miocene to Pliocene, and owing to the variable nature of the beds and the scarcity of fossils, no precise determinations have yet been made of the periods represented.

In east Texas these deposits are known as the *Fleming formation.* The *DeWitt formation* of Deussen, lying west of the Trinity River, is the equivalent of the higher beds of the Fleming farther east and together with the lower

Fleming, is more or less the equivalent of the Oakville, Lapara and Lagarto formations farther to the southwest.

Fleming

The Fleming formation consists of clays and sands with quantities of calcareous concretions. The clay is grayish, yellowish-green, pink, or brown in color, and weathers to black, sticky, clay soil. There are concretions of fine to medium-grained sandstones of large size and rough, irregular outline. The cementing material of this sandstone is generally lime. The percentage of sand in the basal Fleming increases to the westward. The thickness of the Fleming is probably not less than 1,500 feet.

Vertebrate fossils of late Miocene or possibly early Pliocene age are found in the Fleming in the vicinity of Burkeville, Newton County, and of an age ranging from middle Miocene to early Pliocene at Cold Springs, San Jacinto County, and near Navasota, Grimes County.

Brackish water fossils of probable early Pliocene age were found in wells at Terry, Orange County, at depths of 3,000 to 4,000 feet. In the Galveston deep well upper Miocene marine fossils were found at depths of 2,168 to 2,920 feet, and from 1,506 to 2,150 feet the fossils found were probably Pliocene in age. The upper Miocene strata in the Galveston well consist of green clays, indurated fine gray sands, dark-colored clays with lignitized wood, sandy clays, shell conglomerates, and also clays with lime nodules. The Pliocene in this well is made up of clay and sand, of various shades of gray, green, or brown.

Marine Miocene fossils were found in a well at Batson, Hardin County, at a depth of 323 feet, and in oil-bearing sand at Saratoga, Hardin County, at depths of 1,140 to 1,154 feet.

Oakville

The Oakville formation is made up of sands, grits, and clays. Fossils of land vertebrates found in the upper portion of the Oakville are of Upper Miocene age. The grits and coarse sands of the Oakville are cross-bedded, with some beds of clay, but often with balls, nodules, or lenses of clay imbedded in the grit. There is some hard and firm sandstone, but the beds are mostly very poorly consolidated. Local beds of conglomerate occur.

Lapara

The Lapara formation consists of sands and clays interbedded and somewhat cross-bedded. The sands are coarse and sharp, often forming grits, and including pebbles of clay and calcareous concretions. The clays are jointed and of vàrious colors—light red, green, brown, purple—and in some localities appear as a conglomerate of clay pebbles. The mammalian fossils of the Lapara are of the same age as the Blanco Middle Pliocene of the Llano Estacado.

Lagarto

The Lagarto formation comprises beds of limy clay, sand, sandstone, and conglomerate. It outcrops in Nueces, Duval and Webb counties, and is of upper Pliocene age.

The Coastal Plain Miocene and Pliocene outcrops in Newton, Jasper, Tyler, Polk, San Jacinto, Walker, Montgomery, Grimes, Waller, Washington, Austin, Fayette, Colorado, Lavaca, Gonzales, DeWitt, Victoria, Goliad, Karnes, Bee, Live Oak, McMullen, Nueces, Duval, Webb, Zapata, and Starr counties.

NORTHWEST TEXAS

Miocene and Pliocene

The High Plains of northwestern Texas contain some thin and generally unconsolidated beds of clays, sands and gravels. These are the deposits of streams which formerly flowed eastward from the mountains of New Mexico and Colorado. Some of these are of Middle or Lower Miocene age, and are known as the *Panhandle beds*. Other beds belong to the Upper Miocene and are known as the *Clar-*

endon ("Loup Fork," or Goodnight) beds. Some are of Middle Pliocene age, and have been called the *Blanco beds.* None of these beds has a known thickness of much more than one hundred feet.

QUATERNARY

	Eastern Gulf Coastal Plain	Western Gulf Coastal Plain	Northwest Texas
	Recent	Recent	Recent
Pleistocene	Port Hudson-Columbia (Beaumont or Coast Clays)	Port Hudson-Columbia, Equus beds	
	Lafayette, Lizzie	Uvalde, Reynosa	Tule, Seymour

Pleistocene (Possibly Including Some Pliocene)

Most parts of Texas have some deposits of later Pliocene(?) and Pleistocene age. These consist of three kinds: (1) the Lafayette sands, clays and gravels forming the cappings of the upland surfaces over much of Texas, and also forming the deposits of the higher stream terraces in the Edwards Plateau; (2) the second bottoms or terraces of Texas streams, generally known as the Columbia deposits; (3) the clays and sands at the surface and underlying the surface of the low flat country forming a belt from fifty to a hundred miles wide along the Gulf Coast, known as the Port Hudson or Coast clays.

Lafayette

The Lafayette is also known as the *Uvalde, Reynosa, Lizzie, Seymour,* and *Tule* or *Rock Creek formations.* These deposits are primarily sands and to a lesser extent rounded, water-worn gravels, and clays, which are locally pure when they are found in thin layers, but are more often clays mixed with sand. Gradations from pure clay into pure sands through all intermediate stages of sandy clays and clayey sands occur, but the larger part of the deposits is of sands and clays mixed in various proportions.

The deposits are practically never well stratified and seldom well-assorted. Cross-bedding and pockety structures are common. In many places the bedding is irregular and wavy, exhibiting a structure closely resembling minor crumpling between the strata and such as is often seen in alluvial and lake sediments. This crumpling is seldom recognized except when thin layers of clay are interbedded with sandy material. The gravels are either unassorted and unstratified or are found in pockets in the clays or sands, or else exhibit rude stratification often in thin layers running out into the other materials; in some places, only single lines of pebbles running out into the clays and sands.

The Lafayette clays, sands and gravels do not make up persistent strata distinct from one another, which can be traced for long distances. Rather do they interleave and dovetail with each other, so that the section of the deposits at one place is not like that at another place, even a short distance away. A deposit of sand, gravel, or clay is local in its distribution and lenticular in its form. Deposits, whether considered in a single section or over the region as a whole, are markedly heterogeneous in composition and distribution. But they are also homogeneous in the sense that a section in one locality consists of about the same materials with the same structure as will be found in a section of a far distant locality, though in different relationships and order of succession. As a whole, therefore, they may be aptly described as a "homogeneous-heterogeneous" complex which is a unit distinct from any of the other formations, easily distinguishable from the underlying deposits and in its make-up implying common conditions of origin.

The Lafayette gravel is variable in lithologic character in different regions, the variation being determined by differences in the nature of the materials in the several drainage areas from which dèbris comprising it was derived. On the Llano Estacado and Panhandle High Plains and the region lying north, east, and southeast of the Edwards Plateau, the gravels and conglomerates are of granites, and other igneous rocks, metamorphic rocks, quartz, jasper, flint, limestone, and ferruginous pebbles and concretions. To this phase the names Lafayette, Tule or Rock Creek, Seymour, and Lizzie have been applied. Much of this gravel came from the western mountains and from the Trinity conglomerate of the Comanchean and from the Triassic conglomerate. In the eastern region, where the areas drained are largely made up of red clays and ferruginous sands and iron ores, the formation consists largely of red, ferruginous sands, silts and conglomerates, with, however, a sprinkling of all the rocks noted above. In the region south of the Balcones escarpment the formation (here known as the *Reynosa or Uvalde*) is largely made up of limestone and chert gravels derived from the erosion of the Edwards limestone, and of whitish adobe clays. In the Rio Grande basin the deposits (known as *Reynosa*) consist of gravels of all kinds of resistant rocks encountered by the Rio Grande and its tributaries in their courses in Colorado, New Mexico, Texas, and Mexico.

The upland deposits of the Lafayette are generally quite thin. In most regions they seldom have a thickness as great as 100 feet, but on the Llano Estacado and Panhandle High Plains they may locally be as much as 300 feet thick and in the basins between the Trans-Pecos mountains they are in some places probably over 1,000 feet thick. On their Gulfward margin, where they unconformably overlie the Fleming or its westward equivalent and are unconformably overlain by the Port Hudson, their thickness ranges up to as much as 500 and perhaps even as much as 800 feet. The Lafayette unconformably overlies at one place or another practically every older formation of Texas.

The Uvalde deposits form the higher terraces along the streams trenching the Edwards Plateau. South of the Balcones escarpment the Uvalde terrace deposits merge into the Uvalde upland deposits. The Lafayette was mainly confined to the regions near the present stream valleys in the Grand Prairie region. Here, during Lafayette time, the major stream, the Brazos, was a transporting and eroding, rather than a depositing stream.

Pleistocene fossils have been found in the Tule or Rock Creek beds of the Llano Estacado, the Seymour deposits of Baylor, Wilbarger and Knox counties, and in the Lizzie gravels of Wharton County. It is very difficult to separate later Pliocene from earlier Pleistocene deposits and for this reason the two are here grouped together under the general name of the Lafayette.

Port Hudson-Columbia

These formations are also known as *Beaumont* or *Coast clays* and *Equus beds.*

The region of the Coastal Belt is covered and underlain by the Port Hudson, Beaumont, or Coast clays, which unconformably overlie the Lafayette and are covered in the stream valleys and in the shallow water zone along the Gulf coast by Recent deposits. The Port Hudson consists of blue, yellow, brown, and in places reddish, limy clays, with numerous small lime concretions and some local lenses of sand and sandy clay. It does not exceed 800 feet in thickness. The Port Hudson contains a considerable quantity of cypress wood and shells of molluscan species still living in the shallow waters of the Gulf.

The Columbia River deposits form the material of the second bottom terraces of the main streams. The second bottoms of the streams south of the Balcones escarpment extend as far upstream as the foot of the escarpment. On the Brazos River they extend well into the north-central plains area; on the Trinity they extend nearly to its source; on the Red River they extend nearly to the foot of the escarpment of the Llano Estacado, and nearly to the heads of the Sabine, Neches and Angelina rivers. Gulfward the second bottoms merge into the Port Hudson deposits of the low, flat Coastal Belt. At the base of the second bottom alluvial deposits there is generally a layer of gravel derived from the erosion of the Lafayette. The Columbia deposits are mainly clays and silts of various colors, of which shades of blue, black and red predominate, containing small limy concretions, sands, and some gravel. Cypress wood, clam shells, and fossil bones of elephants (mammoths), mastodons, horses and ground sloths are frequently found. In the western part of the Gulf Coastal Plain the Port Hudson has been called the Equus beds from the fossil bones of horses found in it. The Equus beds consist largely of ash-colored limy clays, and gravels.

The lower portion of the deposits here grouped together as the Port Hudson-Columbia was made during the interval of post-Lafayette erosion which followed the deposition of the Lafayette and preceded the later sinking of the land surface. This portion contains the gravels forming the bottom layers of the second bottom terrace deposits and some of the gravel, sand and clay layers which cannot be distinguished from the underlying Lafayette deposits in that portion of the Gulf Coastal Plain where the Lafayette is overlain by the Port Hudson. These cannot well be separated at present from the deposits of strictly Lafayette and Port Hudson age.

On the present land area of Texas the stream flood plain deposits, subject to overflow in times of high water, are of Recent origin. Along the Gulf coast the deposits of the coastal marshes, tidal swamps and flats, shore line, estuaries, deltas, and shallow waters of the Gulf are of Recent time. The surficial fine soils of the Llano Estacado and Panhandle High Plains are Recent deposits by wind, or eolian agency.

Recent

Another sort of action is going on in Recent times in the arid and semi-arid western portions of the State, and that is the formation of "caliche." "Caliche" is a deposit of lime formed by the evaporation upon reaching the surface of waters carrying calcium carbonate. These waters rise through the pores of the soil by capillary action and upon reaching the surface are evaporated and leave their mineral matter as a precipitate which serves to cement together the soil materials. The "cap rock" of the High Plains is one of these "caliche" deposits, but many others occur in western Texas.

In the more moist portions of the State, particularly in eastern Texas, sands and gravels are often cemented by iron oxide precipitated from the waters of springs and marshes.

Dust, removed by the wind from dry bare surfaces, is transported, sometimes for long distances, and deposited in more moist regions where it is caught and held by a thick covering of vegetation or by wet surfaces and bodies of water. In the arid western region vast quantities of dèbris ranging in size from large boulders to fine silt, are swept out of the mountain canyons by flood water during times of heavy rainfall and accumulated in deposits along the foot of the mountains upon checking of the stream velocity, brought about by decrease in gradient and evaporation and seepage of the waters on the dry, thirsty plains. If these mountain streams drain into a basin without outlet to the sea, a portion of the finer materials transported by the streams is swept down to the lowest part of the basin where it forms mud flats when wet, and playas when dry. These dry playas afford much dust which is removed by the winds and deposited elsewhere. The mineral matter carried in solution by the waters which reach the mud flats is deposited upon the playa surfaces when the waters dry up. Salt, gypsum, soda, potash, and other lime compounds are the most common chemical sediments of the playas or "dry lakes." In regions of sandy soils, dunes are often formed by wind action and these dunes or "medanos" are quite common in the southernmost part of Texas, where much of the sand is derived from the sand bars and shore line deposits washed up by the waves.

IGNEOUS ROCKS

Igneous rocks are rocks which once existed in a liquid molten state and have since cooled to the solid state. They are of three classes: (1) rocks which have cooled beneath the surface of the earth, generally coarse-grained, forced into other rocks, and known as plutonic or intrusive rocks; (2) rocks which have reached the surface of the earth and have there solidified, generally fine-grained, called extrusive or volcanic rocks or lavas; (3) fragments of rocks of all sizes which have been blown out of volcanoes and often form layered or stratified deposits called volcanic ash or tuff, when fine; or volcanic bombs or cinders, volcanic breccia or agglomerate, when larger. Igneous rocks are further classed, according to chemical composition, as acidic, or lighter-colored and lighter weight rocks; and basic, or darker-colored and heavier rocks. The common minerals in igneous rocks are quartz, feldspar (orthoclase and plagioclase), mica (biotite and muscovite), feldspathoids (leucite, nepheline, and others), and iron-magnesian minerals (olivine, hornblendes, and pyroxenes, augite, etc.). A porphyry is an igneous rock with larger crystals (called phenocrysts) imbedded in a finer-grained matrix. A pegmatite is a very coarse-grained rock containing only quartz and feldspar, or quartz, feldspar and mica with or without minor quantities of other minerals.

Intrusive or plutonic rocks occur in masses of various forms. Stocks, bosses, or batholiths are intrusive masses of various sizes and irregular shapes which have broken into other rocks in an irregular manner. Laccoliths are intrusive masses which arch up the overlying rocks. Intrusive sheets or sills are intruded between layers of other rock in tabular or wedge-shaped sheets. Dikes are tabular masses which break through other rocks and fill cracks or fissures. A volcanic plug or neck is a mass of lava which has hardened in the vent of a volcano.

The names of the commoner igneous rocks will be found in the following table. By the aid of the definitions already given, it may be possible to determine from this table the chief forms, texture, chemical composition and mineral composition of many of the common igneous rocks.

Texas has intrusive, fragmental and volcanic igneous rocks but together they cover considerably less than three per cent of the total area of the State. The known ages of Texas igneous rocks are Pre-Cambrian and late Cretaceous-early Eocene. Other igneous rocks, particularly of the Trans-Pecos region, may be middle Tertiary and Pliocene or Pleistocene in age. The Pre-Cambrian igneous rocks are found in the Central Mineral Region of Llano, Burnet, Mason and other counties, in the Franklin Mountains north of El Paso, and in the Wylie, Carrizo, and Van Horn moun-

TABLE SHOWING THE CLASSIFICATION OF IGNEOUS ROCKS

(Modified from J. F. Kemp)

Form	Texture	Acidic, Excess of light coloured minerals			Composition intermediate between acidic and basic				Excess of dark coloured minerals, Basic		
MINERALS FUSED AND INDISTINGUISHABLE											
Crusts	Glassy	Acid Glasses Obsidian, Perlite			Andesite Obsidian				Basic Glasses, Scorias		
Surface lavas		Pumice, Pitchstone							Trachylyte, Basalt-Obsidian		
MINERALS DISTINGUISHABLE											
		Chief Feldspar Orthoclase			Plagioclase Chief Feldspar				Nepheline, Leucite	No Feldspar	
		Biotite (or) (and) Hornblende			Biotite (or) (and)		Pyroxenes		Pyroxenes	Augite (or) (and) Hornblende	
		(or) (and) Augite			Hornblende					(or) (and) Biotite	
		+Quartz	-Quartz	Nepheline or Leucite	+Quartz	-Quartz	-Olivine	+Olivine	-Olivine +Olivine	-Olivine	+Olivine
Surface	Cellular Glassy	Rhyolite	Trachyte	Phonolite (rare)	Dacite	Andesite	Augite-Andesite	BASALT GROUP			
Lavas	or Felsitic Phenocrysts few	(Felsite)	Felsite	Leucite rocks (very rare)	(Felsite)	Felsite		Basalt	Series of rare	Augitite	Limburgite
Dikes Intrusive	Porphyritic Phenocrysts prominent	Rhyolite-Porphyry Quartz-Porphyry	Trachyte-porphyry	Phonolite-porphyry	Dacite-porphyry	Andesite-porphyry	Augite-Andesite porphyry	Basalt-porphyry	Basaltic rocks with nephelite (or) (and) leucite	Augitite-porphyry	Limburgite-porphyry
Sills, Laccoliths	**Porphyritic Phenocrysts** predominant	Granite-porphyry	Syenite-porphyry	Nepheline-Syenite-porphyry	Quartz-diorite-porphyry	Diorite-porphyry	Gabbro-porphyry	Olivine-Gabbro-porphyry		Pyroxenite-porphyry	Peridotite-porphyry
							GABBRO GROUP				
Laccoliths, Batholiths	Granitoid	Granite	Syenite	Nepheline-Syenite	Quartz-diorite	Diorite	Gabbro	Olivine-Gabbro		Pyroxenite	Peridotite
Beds	Fragmental	Rhyolite tuffs and breccias	Trachyte tuffs and breccias	Phonolite tuffs and breccias	Dacite tuffs and breccias	Andesite tuffs and breccias	Andesite tuff and breccias	Basaltic tuffs and breccias			
Percentage of Silica (SiO_2)		80-65%	65-55%	60-50%	70-60%	65-50%	65-50%	55-45%	50-40%	55-30%	

tains near Van Horn. The late Cretaceous-early Eocene igneous rocks are widely distributed in the mountain region of Trans-Pecos Texas. Those occurring in a belt just east and south of the Balcones escarpment from east of the Colorado River westward to the Rio Grande are usually referred to late Cretaceous-early Eocene age.

Pre-Cambrian Igneous Rocks

In the Central Mineral Region the igneous rocks are all intrusive and are mainly granite with a small percentage of diorite, quartz-porphyry, peridotite or pyroxenite, and gabbro. The older granite has been metamorphosed into gneiss and all the other igneous rocks, except the younger granite and pegmatites, have also been metamorphosed. The rocks have the forms of bosses or batholiths and dikes. Many of the dikes are of pegmatite. The very coarsely crystalline pegmatite of Barringer Hill, Llano County, is one of the most remarkable pegmatites of the world and is famous for the rare-earth minerals found in it.

There is a red rhyolite-porphyry lava of Pre-Cambrian age in the Franklin Mountains. Sills and pegmatite dikes and possibly intrusive masses of other forms are found in the Pre-Cambrian of the Carrizo Mountains, and also intrusions of diabase, quartz-porphyry, and rhyolite. In both these regions of Trans-Pecos Texas at least a part of the igneous rocks has been metamorphosed. At Mica Tanks, in the Van Horn Mountains, granitic and amphibolitic gneisses, which are metamorphosed igneous rocks, have been found and also pegmatites.

Late Cretaceous-Early Eocene Igneous Rocks

Two kinds of igneous rocks are found in a belt along the Balcones escarpment, most of the occurrences being just east and south of the escarpment. The most common is basalt, intrusive, extrusive and fragmental. Phonolite also occurs in Uvalde County as intrusives and volcanic plugs. Both of these rocks were probably erupted by volcanoes, the sills and dikes being offshoots from the volcanic plugs.

Basaltic materials in the Austin chalk and Taylor marls of the Austin and Thrall regions are generally thought to be thin lava flows or tuffs and volcanic ash in the sea of those times. If so, volcanic activities must have continued until after the close of the Taylor marls time, for the plugs are intrusive in both the Austin chalk and Taylor marls. This belt is a portion of a larger belt of igneous activity which extended from the Arkansas River at Little Rock, Arkansas, west-southwestward to beyond the Rio Grande; a belt in which the igneous rocks are characterized by the presence of the minerals nepheline and augite.

Igneous Rocks of Trans-Pecos Texas

Igneous rocks are here very abundant but as yet have been studied very little. They are intrusive, extrusive, and fragmental. Most of the intrusive rocks belong to the syenite and granite groups. The lavas are largely the volcanic equivalents of the syenites and granites, namely, phonolites, trachytes and rhyolites. Andesites and basalts are also fairly common. The greatest area of lava is that stretching from just south of the Texas and Pacific Railway southward to the Big Bend of the Rio Grande. In this belt rhyolite is probably most common but other kinds of lavas also occur. The basaltic lavas, at least in part, seem to be latest in age and may be later Cenozoic (Pliocene or Pleistocene). The rhyolitic lavas in the northern Davis and Barilla mountains are very late Cretaceous or early Eocene in age, as is shown by the plant fossils in the associated tuffs. There may also be middle Tertiary igneous rocks but this is not certain.

Most of the igneous rocks of the Trans-Pecos region occur south of the line of the Texas and Pacific Railway. North of that railway the igneous rocks have been studied only in the Van Horn and El Paso regions. The only basalt known north of the line of the Texas and Pacific railroad occurs both as an intrusive rock and lava flow in Cox Mountain, twelve miles north of Eagle Flat station and just west of the Diablo Plateau. In the Sierra Blanca are granite and rhyolite, in the Diablo Plateau are two intrusive stocks of diorite and quartz-diorite, in the Franklin Mountains are granite and andesite-porphyry intrusions, and in the Hueco Mountains are syenite-porphyry intrusions. In the Cerro Alto, Cornudas, Sierra Tinaja Pinta, and Black mountains are igneous rocks which have not yet been studied.

South of the line of the Texas and Pacific railroad the igneous rocks, so far as known, occur in the various ranges as follows:

Barilla Mountains—Lavas and tuffs of rhyolite.

Carmen Range—Basalt lava on the east flanks near the junction of Maravillas Creek with the Rio Grande.

Chinati Mountains—Lavas, tuffs, dikes, intrusive sheets, and laccolithic bosses of rhyolite, andesite, granite and diorite.

Chisos and neighboring ranges—Lavas, tuffs, dikes, intrusive sheets and laccolithic bosses of rhyolite, dacite, grorudite (a variety of quartz-porphyry), quartz-porphyry, quartz-diorite, porphyritic andesite, diabase, obsidian, basalt and felsite. There is a volcanic plug of diabasic rock just west of Rosillos Mountains.

Cienega Mountain—This mountain is a laccolithic dome of granite rock.

Davis Mountains—Intrusive and volcanic rocks and tuffs of nepheline-syenite, elaeolite-syenite, phonolites, trachytes with quartz, paisanite (a rare variety of quartz-porphyry), andesite, basalt, rhyolite and rhyolite-porphyry.

Eagle Mountains—Lavas of pitchstones and other rocks.

Iron Mountain, north of Marathon—Intrusive stock of syenite-porphyry.

Mount Ord Range—Intrusions of granite and syenite and lavas and tuffs of rhyolite.

Quitman Mountains—Intrusives of granite, syenite, aplite, granite-porphyry, diabase and augite-porphyry. Lavas of felsite-porphyry or keratophyre.

Santiago Range—Intrusive pulaskite (a variety of syenite).

Sierra Bofecillos—Lavas of augite-andesite.

Tierra Vieja Mountains—Intrusives of syenite-porphyry and lavas of nepheline-tephrite (a rock resembling basalt) and quartz-pantellerite (a peculiar and rare rock rich in soda, of the rhyolite group).

Van Horn Mountains—Intrusive dikes of diabase and basalt and lavas of andesite.

Wylie Mountains—Lavas of andesite and basalt, according to Osann.

East of Santiago Range and south and southeast of Marathon—Intrusive rocks of acidic and intermediate composition, not yet studied.

CHAPTER III

GEOLOGIC HISTORY

BY C. L. BAKER

PRE-CAMBRIAN

The earliest records of earth history found in Texas are afforded by the Pre-Cambrian rocks in the Central Mineral Region and the western part of the Trans-Pecos country. The rocks found here belong to the younger Pre-Cambrian. Every variety of sediment is found and in both regions are igneous rocks also. In the Franklin Mountains, north of El Paso, the Pre-Cambrian sediments and lava flows were metamorphosed but were not affected by strong earth movements before the deposition of the overlying Cambrian. In the Van Horn region the Pre-Cambrian was not only metamorphosed but was also tilted to a nearly vertical position by earth movements. The older series, the Carrizo schists, was more metamorphosed than the younger Millican sandstone, but both formations have been strongly tilted. In the central region there is an older intrusive granite, metamorphosed to gneiss, and a series of sedimentary rocks, changed to schist, intruded by a later granite, which is not strongly metamorphosed. These rocks have been folded into two rather broad synclines with an intervening anticline.

The Pre-Cambrian sediments were derived from the erosion of pre-existing land masses, the location of which is not known. They were deposited in bodies of water, which were either a portion of the sea or lakes upon the land. The presence of limestone and especially graphite indicates that life probably existed during that time, but the nature of the life is unknown. The sediments are made up of materials derived from older sedimentary and igneous rocks and of materials of organic origin. Both surface lava flows and intrusive igneous rocks which solidified at a considerable distance beneath the surface are known in the Pre-Cambrian of Texas. In both the Van Horn and Central Mineral regions mountain ranges came into being in later Pre-Cambrian time; in the Franklin Mountains there is no evidence of Pre-Cambrian mountains. Following the deposition of the sediments the Pre-Cambrian region became dry land and was very greatly eroded, so much so, in fact, that in the Central Mineral Region the core of the old mountain range and the deep-seated intrusive igneous rocks were laid bare.

THE PALEOZOIC ERA

Cambrian Period

The great period of erosion referred to continued through Lower and Middle Cambrian time and the Pre-Cambrian rocks of Texas were exposed as a part of a great land area which extended crescentically from beyond Lake Superior on the north along the Appalachian Mountains on the east to the Grand Canyon region of Arizona on the southwest and to the north again beyond the Black Hills of South Dakota and northern Wyoming. Over this old land mass, which seems to have been brought to a low and nearly featureless plain by the long-continued erosion during the later Pre-Cambrian and early Cambrian time, the Upper Cambrian sea advanced, reworking the weathered rocks and soils by wave action along the shore of the advancing sea into the basal conglomerate of the Upper Cambrian. Most of the Cambrian rocks of Texas, which are found in the same areas as are the Pre-Cambrian and also in the Marathon region of Trans-Pecos Texas, are composed of materials derived from the erosion of the land; that is, they are mostly sandstones, shales, and conglomerates. But in the Central Mineral Region the upper sediments of the Cambrian contain limestones, or sediments derived from the remains of hard parts of animals and plants. Fossils, or the remains of pre-existing life, are found in Texas for the first time in the Upper Cambrian rocks. The presence of limestone in the later Upper Cambrian indicates a deepening of the sea and clear waters free from land-derived sediment.

Ordovician Period

There was probably a break in the sedimentation at the end of the Cambrian at all places in Texas where Cambrian and Ordovician rocks are now exposed, but in the Central Mineral Region there is no evidence of actual unconformity between the Cambrian and Ordovician. The existence of an unconformity in a series of marine sediments implies that the rocks below the surface of unconformity were uplifted above the level of the sea, followed by erosion of the newly uplifted land area, and then a new submergence beneath the waters of the sea, during which the beds above the surface of unconformity were deposited. Such an unconformity is found between the Cambrian and the Ordovician in the Van Horn region. There appears to be no unconformity in the Franklin Mountains where the Ordovician overlies the Cambrian, but here the Ordovician locally overlies unconformably the Pre-Cambrian rhyolite lava flows, implying either that a portion of the Pre-Cambrian area there had never been covered by the Upper Cambrian sea, or else that Upper Cambrian sediments, once deposited, had been removed by erosion before the Ordovician was deposited.

There are lower and upper Ordovician rocks in the Van Horn and El Paso regions. Only the Lower Ordovician is found in the Central Mineral Region. An unconformity, implying uplift of the Lower Ordovician above the waters of the sea, and its subsequent erosion in Middle Ordovician, separates the Lower from the Upper Ordovician. In the Upper Ordovician there was a re-submergence beneath the waters of the sea in western Trans-Pecos Texas, which was followed by the deposition of the Upper Ordovician.

The Ordovician sediments are limestones deposited in clear, though not very deep waters. Materials derived from land erosion are not plentiful, so that there could not have been nearby land areas of any marked relief.

The history of the Middle and Upper Ordovician in the Central Mineral Region is lost to us. Whether there was deposition or erosion during the later Ordovician is unknown. In the Marathon region the Ordovician history of marine deposition, though fuller and containing the Middle Ordovician, cannot yet be written with certainty.

Silurian Period

Silurian rocks are known in Texas only from the El Paso region, although they may yet be found in the western portion of the Trans-Pecos region south of the Southern Pacific railway. The Silurian of the El Paso region is of Niagaran or middle Silurian age. It is limestone and is probably unconformable on the Upper Ordovician.

Upper Silurian and Devonian and Mississippian Periods

No Upper Silurian sediments have been found in Texas and no Devonian sediments are yet certainly known. Possibly between the end of the Middle Silurian and the beginning of Pennsylvanian time there were several periods of emergence and subsidence produced by broad vertical movements, similar to those known to have occurred in the Trans-Pecos region between the end of the Lower Ordovician and the end of the Middle Silurian. It may be that none of the missing formations was ever deposited and that the Pennsylvanian beds represent a transgression of Gulf and possibly Pacific waters following a long interval during which the land stood relatively very low with respect to the sea.

Pennsylvanian Period

The middle Paleozoic was in Texas largely a time during which the earlier rocks were eroded. The land probably at no time stood very high above sea-level and there were no mountains in Texas. At the beginning of the Pennsylvanian period the land was low and flat. Then the region became again submerged beneath the sea and deposition of limestone, shale, and sandstone took place.

Lower Pennsylvanian deposits are known only in the Central Mineral Region and the Marathon country of Trans-Pecos Texas. In the Marathon region the sedimentation began with the deposition of over three thousand feet of sandstones and shales, with a very small amount of conglomerate. This seems to have been largely a deposit near and upon the land. The only fossils so far found consist mainly of the remains of land plants and of a few marine animals. This was followed by a marine limestone, over which lie shales and sandstones very similar to those of the lower series. In the Central Mineral Region the Lower Pennsylvanian sediments are entirely marine, consisting of shale at the base, limestone in the middle, and another bed of shale at the top, very similar to the lower shale. These may be of upper Mississippian age (St. Louis-Chester stage).

This time of sedimentation was followed by the formation of mountains. The mountain-making movements were more intense in the Marathon country and in the Solitario northwest of Terlingua than in the Central Mineral Region. The mountain foldings of Middle Pennsylvanian age in the Marathon Region were later than the earlier Pennsylvanian foldings in the Central Mineral Region. In the former region the rocks were pressed together in numerous closely-spaced folds which are very similar in structure to those formed at probably the same time in the Ouachita Mountains of west-central Arkansas. In the Central Mineral Region, folding was very gentle and the structures are similar to those produced at the same time in the Arbuckle Mountains of southern Oklahoma. Gentle uptilting of the older rocks probably occurred at the same time in the El Paso and Van Horn regions.

The newly formed mountains were rapidly eroded and were submerged beneath the sea in later Pennsylvanian time. In the western Trans-Pecos region a limestone nearly a mile in thickness was deposited and in the Marathon region shales and limestones covered the much eroded folds of the mountains. In the north-central plains region sedimentation began with sandstones and shales, and was followed by shales and limestones. The land-derived sediments seem to have come from lands to the east and southeast and for this reason it is believed that the mountains of the Central Mineral Region were then continuous with those of southeastern Oklahoma and west-central Arkansas, and perhaps stretched westward to the Marathon mountains. If this old mountain range did exist in the region of northeast and central Texas, it has been completely covered by later sediments.

The oldest sediments later than the formation of these mountains are those comprised in the Millsap division of the Strawn formation. The top of this division is marked by the first bed of workable coal deposited in Texas and now mined at Thurber. The Millsap division was never deposited on the flanks of the Central Mineral Region, but was laid down farther north. The Richland sandstone member of the Strawn, however, overlaps onto the northern flank of the Central Mineral Region. The Richland sandstone indicates farther southward transgression of the sea, brought about probably by both a further sinking of the Central Mineral Region and a lowering of its surface by erosion.

The Pennsylvanian is one of the great periods of coal formation on the earth. Practically all of the coal of the eastern and northern United States was deposited at this time. All of the North American coal of Pennsylvanian age was deposited east of the line of the One Hundredth Meridian. West of this meridian the sediments are more exclusively marine than to the east. This is why a great thickness of limestone was being laid down in Trans-Pecos Texas at the same time that coal, sandstone, shale and limestone were deposited in north-central Texas. The Pennsylvanian coals of north-central Texas were deposited in a region farther west and farther south than any other coals of the same age in North America.

The Pennsylvanian sea of north-central Texas was never very deep and its waters were seldom free from the sand and mud brought to it from land areas on the south and southeast. It was only near the close of the period and then only in the southwestern part of the region that the sea waters became fairly clear from land-derived sediments. The coal beds, found in the Strawn and Cisco formations, were probably formed in regions of coastal swamps, the surfaces of which lay very close to the sea-level. Comparatively rapid oscillations of level must have sometimes taken place, because we find beds of coal directly overlain by limestones containing abundant marine fossils.

We may draw for ourselves a fairly vivid picture of later Pennsylvanian times in north-central and west Texas. To the westward lay a great sea with clear water abundantly teeming with marine animals. On the south and southeast was the land of mountain ranges which came into being earlier in the Pennsylvanian. Between this land and the western sea was a low foreland and shore line, now submerged beneath a shallow sea, now a marshy land covered by forests of the plants of the coal period.

Near the end of the Pennsylvanian time there was a period of mountain formation in west-central Arkansas, southern Oklahoma and the Marathon region of Trans-Pecos Texas. The Cisco formation of north-central Texas was laid down after this period of mountain-making in southeast Oklahoma. South of the Arbuckle and Wichita mountains of Oklahoma the Cisco sediments are red sandstones, conglomerates, and shales, showing by their structures that they were deposited by rivers flowing southward and southwestward from the mountains on a flattish plain much like the country along the shore of the present Gulf of Mexico. Farther to the southwest the Cisco sediments became marine shales and limestones, indicating that they were deposited in rather clear waters of the sea. After great erosion of the older Pennsylvanian rocks of the Marathon region took place the mountain range was submerged beneath the sea and the Gaptank formation was deposited.

Permian Period

The beginning of Permian time in north-central Texas was a continuation without marked interruption of the later

Pennsylvanian. The earliest Permian formation, the Wichita, is very like the Cisco, in the northeast river and shoreline deposits of red color, and in the southwest marine limestones and clays. The northeastern Wichita is noted throughout the civilized world for the strange forms of primitive amphibians and reptiles whose bones are imbedded in its clays, sandstones, and conglomerates. These were land animals, most of which lived part of the time on the land and part of the time in the waters of streams or ponds.

In Trans-Pecos Texas the lower Permian is mainly marine limestone with a smaller amount of shale and the sediments have a thickness of about eight thousand feet. Here again, although the exact relations between the Pennsylvanian and Permian are not yet known, it is probable that there was no great change in conditions between the later Pennsylvanian and the earlier Permian. The Trans-Pecos lower Permian, known as the Guadalupian, is known in North America only in this region and in southern New Mexico.

There was a notable change in later Permian time. The upper Permian sediments consist of red clays, commonly known as "Red Beds," and beds of limestone, gypsum, and rock salt. The gypsum and rock salt were deposited from the substances carried in solution by the sea-water upon the drying up of the sea. "Red Beds" are not confined to the later Permian, but are found in Texas also in the northeastern portion of the Cisco (later Pennsylvanian) and Wichita (earlier Permian) formations and in the later Triassic. The later Permian sea was shrinking and so did not cover as large an area as the earlier Permian sea.

The Mesozoic Era

Triassic Period

Some time during the later Permian or at its close, the Permian sea dried up and the country became once more subject to erosion. A broad, gentle folding took place about this time, during which the great geosyncline underlying the Llano Estacado and a mountain range in the Marathon region were formed. Probably also small gentle folds were formed in north-central Texas. The Lower and Middle Triassic was a time of erosion throughout the State of Texas. In the Upper Triassic there was a renewal of sedimentation in the region of the Llano Estacado or Staked Plains. The Upper Triassic sandstone, shales, and conglomerates were deposited by rivers which probably flowed eastward from the Rocky Mountain region.

Jurassic Period

So far, Jurassic rocks are known only near Malone and Finlay, El Paso County, stations of the Southern Pacific railroad. The rocks of this formation are principally blue and gray limestones with interrelated bands of shales, sandstones, and conglomerates. At the base there are several beds of gypsum. The entire thickness as far as it can be observed is 1,500 to 2,000 feet. The Jurassic composes several hills and the Malone Mountains southeast of Finlay.

The rocks described here represent only the higher parts of the Upper Jurassic, the lower part of the upper, as well as the entire middle Jurassic and the Liassic, being unknown in Texas. It is quite probable that the rest of Texas was subject to long-continued erosion during this period. This erosion must have gone on for a long time because the surface of the entire Texas region was brought to a low and featureless plain.

Cretaceous Period

During the earlier Cretaceous the sea advanced over Texas from the south or southwest and, gradually working over the old soils into beach deposits, advanced more or less steadily northward until it finally reached the Arctic Ocean at the mouth of the Mackenzie River, and covered all the country between the present Rocky Mountains and the western part of Iowa and Minnesota. This sea reached its greatest extent in Austin chalk time, and then in later Cretaceous time began to gradually recede from the region so that probably the entire region again became dry land before the close of the Cretaceous. Near the close of the Cretaceous, the Rocky Mountains were first uplifted and the entire Texas region, with the exception of the western Trans-Pecos country was gently tilted in a southeastwardly direction towards the present Gulf of Mexico. In the western Trans-Pecos region, the country was folded and faulted into a mountain range, the mountain folds were much worn down by erosion, and great volcanic activity occurred, probably lasting into the succeeding, or Eocene, period. Great masses of igneous rocks never reached the surface but broke into the sedimentary rocks and there solidified as crystalline masses. Immense quantities of igneous rocks also broke through to the surface and formed thick and extensive masses of lava flows. At the same time there was also igneous activity in the region between Austin and the Rio Grande.

Sediments of the latest Cretaceous occur in Texas only in the region of the Big Bend of the Rio Grande in southern Trans-Pecos Texas, and east of Eagle Pass. The end of the Cretaceous everywhere in Texas was marked by an epoch of erosion.

THE CENOZOIC ERA

The Eocene, Oligocene, Miocene, and Pliocene periods of the Cenozoic are called the Tertiary and the last two, or Pleistocene and Recent periods, are called the Quatenary. For our purposes, we will divide the Tertiary into the earlier Tertiary, comprising the Eocene and Oligocene periods; and the later Tertiary, comprising the Miocene and Pliocene periods.

The Earlier Tertiary

The earlier Tertiary in west Texas was a time of erosion and the materials removed by erosion contributed to the earlier Tertiary sediments deposited in the region of the Gulf Coastal Plain of east, southeast, and south Texas.

The earliest Tertiary sediment in the Gulf Coastal Plain is a thin limestone, the Midway, deposited by the sea on the eroded surface of the Cretaceous. The Midway was followed by sands, clays, and lignite beds, known as the Wilcox, deposited in coastal marshes except on the Sabine River, where a portion of the Wilcox is marine. The Wilcox was followed by an advance of the sea during which the Mt. Selman and Cook Mountain beds were deposited. Again the sea receded and the Yegua clays, and sand and lignite were laid down in coastal marshes. The sea once more advanced over the land in the Jackson or later Eocene, and deposited marine clays and sands.

It is probable that at no time during the Eocene did the sea of the Gulf of Mexico recede as far as its present shore line. The Wilcox and Yegua land and coastal deposits in all probability merge Gulfward into typical sea deposits.

At the end of the Eocene the sea again probably receded and the Corrigan or Grand Gulf clays and sands were laid down on low coastal lands. The age of the Corrigan is not definitely known but it is generally thought to be Oligocene.

The Later Tertiary

At the end of the Eocene most of Texas became dry land and has remained dry land ever since. It is very possible that a larger proportion of the present area of the State was then a land surface than at the close of the Upper Cretaceous. The only portion of Texas submerged beneath the waters of the Gulf since the close of the Eocene was a relatively narrow fringe along the present Gulf border. All the Oligocene, Miocene, and Pliocene deposits of Texas are of non-marine origin in the region of their outcrops. The Miocene and Pliocene formations carry brackish water and marine fossils when they are encountered in deep drillings near the present Gulf shore and are probably there of estuarine or deltaic origin. But from a line roughly drawn about 50 miles inland from the present Gulf shore, as far northwardly and northwestwardly as the limits of their outcrops, these formations are predominantly stream and wind deposits upon the dry land.

The materials of the Oligocene, Miocene, Pliocene and Pleistocene deposits of the Gulf Coastal Plain were derived from the erosion of the older formations making up the land surface of the State. A small part may have come from Oklahoma, New Mexico and Colorado. The Cenozoic deposits of the interior, notably those of the Llano Estacado, the Panhandle High Plains, the Seymour plateau region, and the sheets of sand and gravel found over the upland surface of a large portion of the country northeast, east, and south of the Edwards Plateau, were for the most part brought down by streams from the mountains of New Mexico, Colorado, Trans-Pecos Texas, and possibly Oklahoma.

The land deposits of the Fleming clays and sands were deposited on top of the Oligocene in the Gulf Coastal Plain. The Fleming is middle or late Miocene to Pliocene in age. If the Corrigan is Oligocene, there is a "lost interval" of non-deposition between it and the Fleming. The Fleming passes Gulfward into marine deposits and there are later Pliocene deposits of marine origin underlying the country near the Gulf Coast which do not outcrop in Texas. There are three thousand feet of Miocene and later deposits beneath the sea-level on Galveston Island, and probably something like the same thickness of deposits of similar age underlying the entire Gulf Coast region from Sabine Pass to the mouth of the Rio Grande.

Sedimentation began in northwest Texas in the early part of the Miocene when streams flowing eastward from the Rocky Mountain region made deposits of sands, clays, and gravels. Deposits laid down on the land were also formed in the Staked Plains region during the Pliocene.

Pleistocene Period

It is hard to draw the line between Pliocene and Pleistocene deposits in Texas. This is because the later Pliocene and earlier Pleistocene deposits exposed in Texas are loose beds of sands, gravels, and clays which carry few fossils. and we as yet know so little about the exact age of the fossils that are found, that we cannot draw a sharp line of age distinction between the deposits which contain them. The late Pliocene(?) and early Pleistocene deposits are grouped together here because they were both formed as a consequence of a series of events which, happening at this time, are largely responsible for the present surface features of the Texas region.

Near or at the close of the Pliocene the mountains of New Mexico and Trans-Pecos Texas were again uplifted. In the Trans-Pecos mountain region the rocks were again folded and huge blocks of the earth surface were uplifted along lines of great dislocations or faults. The mountains of Trans-Pecos Texas as we see them today were formed at this time by these movements. Since then the mountains of New Mexico and Trans-Pecos Texas have been greatly eroded and debris from them was spread as a thin sheet of sands, gravels, and clays over nearly the whole of Texas. The spreading of this loose mantle as stream deposits was aided by a gentle tilting of all the Texas region east of the mountains in a southeasterly direction towards the Gulf. At probably the same time as the western mountains were being uplifted, the Balcones escarpment between Austin and Del Rio was being formed by a fault which lowered the Gulf Coastal Plain region below the level of the Edwards Plateau. Remnants of these deposits of sand and gravel, known as the Lafayette, are still found in all parts of Texas except on the surface of the Edwards Plateau and the summits and bedrock slopes of the Trans-Pecos mountains. Gulfward, the Lafayette deposits pass beneath the level of the sea. The deposits of the Lafayette epoch are found best and most extensively preserved today in the capping of the Llano Estacado and Panhandle High Plains, and of the Seymour Plateau east of the Staked Plains (in Baylor and adjoining counties), in the basins between the mountain ranges of the Trans-Pecos region (where they sometimes attain a thickness of more than a thousand feet), and on the eastern flanks of the easternmost of the Trans-Pecos mountains, west of the Pecos River.

When the Lafayette was deposited the Pecos River did not exist, else the deposits would have been transported down the course of that present river instead of across its present course. In fact, all of the rivers of Texas except the Rio Grande, the lower end of the Pecos, the Colorado, the Brazos, the Canadian, and possibly the Red have cut their valleys since the Lafayette epoch. All the canyons in Texas, including the Tule and Palo Duro canyons of the Staked Plains, McKitterick canyon of the Guadalupe Mountains, Madera canyon of the Davis Mountains, the Santa Helena and other canyons of the Rio Grande, the canyon of the Pecos, and the gorge of the Colorado above Austin, have been cut since the beginning of the Lafayette epoch.

Lafayette deposition was followed by erosion, which has continued over almost all of Texas until the present day. At the close of Lafayette time, the land surface was nearly flat with only the Trans-Pecos mountains, the Edwards Plateau, and a few east Texas iron ore hills rising above the plain covered by sands and gravels. The Lafayette-covered plain sloped gently away from the western mountains toward the Gulf of Mexico.

After Lafayette time the rivers of the Gulf Coastal Plain cut broad valleys in the old Lafayette plain, numerous tributaries were formed which roughened the surface of the Coastal Plain, the headwaters of the rivers by their erosion formed the rough country of the north-central plains. The bounding escarpments or "breaks" of the Llano Estacado and Panhandle High Plains, the mesas, buttes, and cuestas of the Grand Prairie and the inner margin of the Edwards Plateau were formed by erosion; that is, by a gradual removal under the influence of rain. The Rio Grande and the Pecos continued during all this time to deepen their canyons.

Then along the Gulf margin the land sank once more beneath the Gulf waters, the lower end of the Coastal Plain rivers were drowned and became estuaries of the Gulf, and a broad belt of clays and sands was formed along the present Gulf margin. These events occurred during the Port Hudson epoch. Later the land emerged from beneath the Gulf and formed a very low, almost perfectly flat, plain which now extends inland from fifty to one hundred miles from the present Gulf shore. The rivers of the Coastal Plain cut terraces in the deposits formed in the former estuaries along their valleys and again deepened their channels.

Recent Epoch

The Recent epoch is one of widespread erosion of Texas land and the eroded materials are being transported to the Gulf by the rivers and there being deposited below the level of the tide. The waves when they break on the shallow shelving bottoms wash up the sands and form the bars, spits, and barrier beaches which are so marked a feature of the Texas coast. It may be that a recent slight submergence of portions of the Texas coast has taken place, causing the estuaries at the mouths of several Texas rivers. If so, the submergence has not taken place uniformly all along the Texas coast, for there are no estuaries at the mouths of the Brazos and Rio Grande rivers.

CHAPTER IV

ECONOMIC MINERAL PRODUCTS

BY J. A. UDDEN AND C. L. BAKER

METALLIC

Silver

Since 1882 it is estimated that more than $8,000,000 worth of silver has been produced in the State. Most of this has come from the Shafter mine. The ore in this mine occurs in chambers of various dimensions in the Permian limestones underlying the Comanchean Cretaceous, a few miles west of Shafter. These chambers are evidently ancient underground caverns which have been filled by the ore and by other siliceous, lean material. These chambers are connected by more narrow leads, where the ore body is often more sharply marked off from the unaltered ledges of the country rock. The body of the ore is mostly a yellow, somewhat porous, rock-like mass of siliceous material in which crystals of calcite and galena are also seen. In the average run, there is only about 3 per cent. of carbonate of lime and from 45 to 50 per cent. of silica in the ore. The percentage of calcareous material increases toward the wall of the ore bodies and it usually also increases with the amount of galena which is present. The bulk of the silver is in the form of a chloride dispersed through the body of the ore. But there are also pockets of galena rich in silver. This is sometimes altered to cerussite. Sphalerite, quartz, and malachite are sometimes found with the other minerals.

The Hazel mine in Culberson County is credited with the production of perhaps two million dollars worth of silver. The ore occurs in this mine in association with a vein which cuts the Van Horn sandstone of the Cambrian series. This vein also carries gray copper. A prospect worked for some time in the hills west from Altuda, generally known as the

Bird mine, has produced some very rich silver-bearing galena. This ore is like that in the Shafter mine, evidently filling fissures and old cavernous places in Permian limestone. Other silver prospects are known in the country north of Allamore and in the mountains north of El Paso, in El Paso County. Some very rich ore was once taken out of some mines in the Quitman Mountains, south of Lasca, and at one time some rich silver ore was shipped from openings farther south in these mountains. Silver has been found in many other prospects in El Paso, Culberson, Presidio, and Brewster counties.

Quicksilver

Since 1900, quicksilver has been mined in the southern part of Brewster County. It is estimated that the value of the quicksilver so far taken out is more than $4,000,000. The mines are in the Terlingua district and the chief production has come from the Mariposa mine and the Chisos Mining Company mine, the W. K. Ellis mine, the Big Bend mine, and the New Almaden mine. The quicksilver occurs in the form of cinnabar, which, for the most part, is found in calcite veins, in the limestones of the Comanchean Cretaceous, and in the flags and marls of the Upper Cretaceous. Some andesite dikes and sills have also been found to contain the ore. The first mining was done on some calcite veins which cut the limestone underlying the Del Rio clay. Some of these deposits were very rich. The ore has been found over an area some thirty miles from east to west and some twenty miles from north to south. In nearly all the localities where the ore has been discovered, it seems to have a structural relation to the formations, resembling that of oil and gas. In the old Mariposa mine the largest deposits occur on an arrested monocline, the dipping limb of which continues toward the south for two or three miles, and the greatest deposits seem to have been lodged against the lower surface of the Del Rio clay at the highest point where this monocline ends and is continued by a structural terrace. In the Chisos mine most of the ore has been taken from the southeast end of a broken, plunging anticline. In this mine, where this anticline itself is bent transversely by a strong flexure, it has also been noted that the richest ore is held below compact layers of the marly beds alternating with limestones. At the north end of the Mariscal Mountain, which likewise is a flexed and plunging anticline, a very good prospect is now successfully worked. The dome-like structure of the Christmas Mountains also contains some

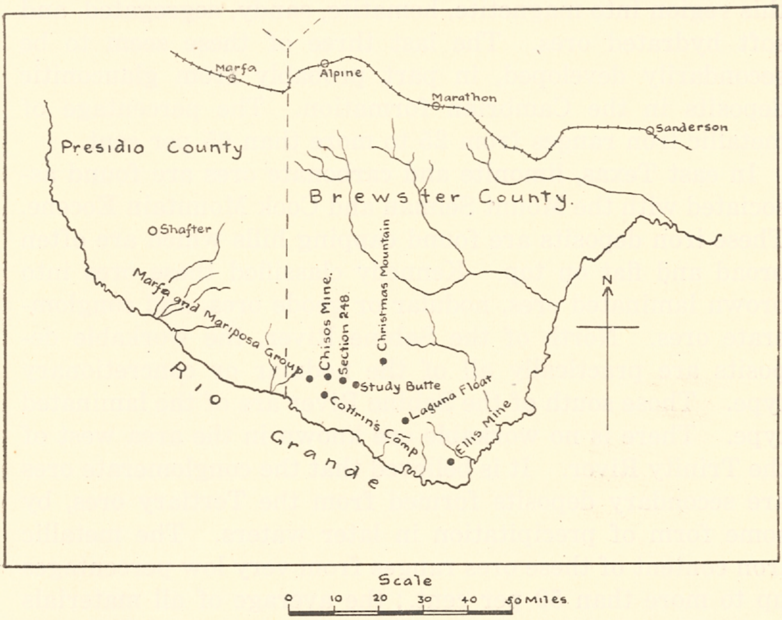

Figure 3.—Sketch map showing localities of quicksilver ore in the Terlingua District.

prospects, one near the crest of the dome and another under the shales on its west side. Other prospects are located in and near some well-marked fault lines, such as the locations worked north of the Mariposa mine and some locations on Terlingua Creek. The ore in Study Butte is apparently an accumulation which has followed an intrusive sheet or dike and has been retained partly in the intrusive itself, and partly in the shales overlying the intrusive.

Iron Ore

Iron ore occurs chiefly in two formations in this State; in the Pre-Cambrian of the Central Mineral Region and in the Tertiary of the Coastal Plain. The magnetite deposits of Llano, Mason and Burnet counties occur in the Valley Spring gneiss. Typically, these are layered, and occur in somewhat schistose rock. None of these has as yet been developed commercially. Comstock classified the ores of this region into magnetite, hematite, sandy, segregated, and soft hydrated ores. The last three of these seem to be secondarily developed, in part probably from glauconitic deposits in the Cambrian formation. The percentage of metallic iron ranges from 25 to more than 65 per cent.

In east Texas, limonite and carbonate ores are found associated with the Mount Selman and Cook Mountain Eocene. These iron deposits are found capping hills which are often broad and flat on top. Kennedy classified these ores into brown laminated ores, nodular or geode ores, and conglomerate ores. North of the Sabine River, the workable deposits are practically all of the nodular or concretionary type. Those south of the Sabine River are of the laminated type. There is no workable ore known in the area west of the Trinity River. It is believed that the conglomerate ores are secondary deposits formed from the Tertiary ores, by some form of precipitation in later waters. The metallic iron content of these ores ranges from very low percentages up to more than 59 per cent.; the average of all materials tested probably being near 30 or 35 per cent. The iron area in East Texas covers about 1,200 square miles in the counties of Anderson, Cass, Cherokee, Gregg, Henderson, Marion, Morris, Smith, Upshur, and Wood. According to some estimates, about $3,000,000 worth of pig iron has been produced in iron furnaces in this region. A few years ago two cargoes of ore were shipped to be mixed with other ores in some furnaces in Pennsylvania.

Lead

The production of lead in Texas is limited to a total of less than 400 tons. This production has come mostly from

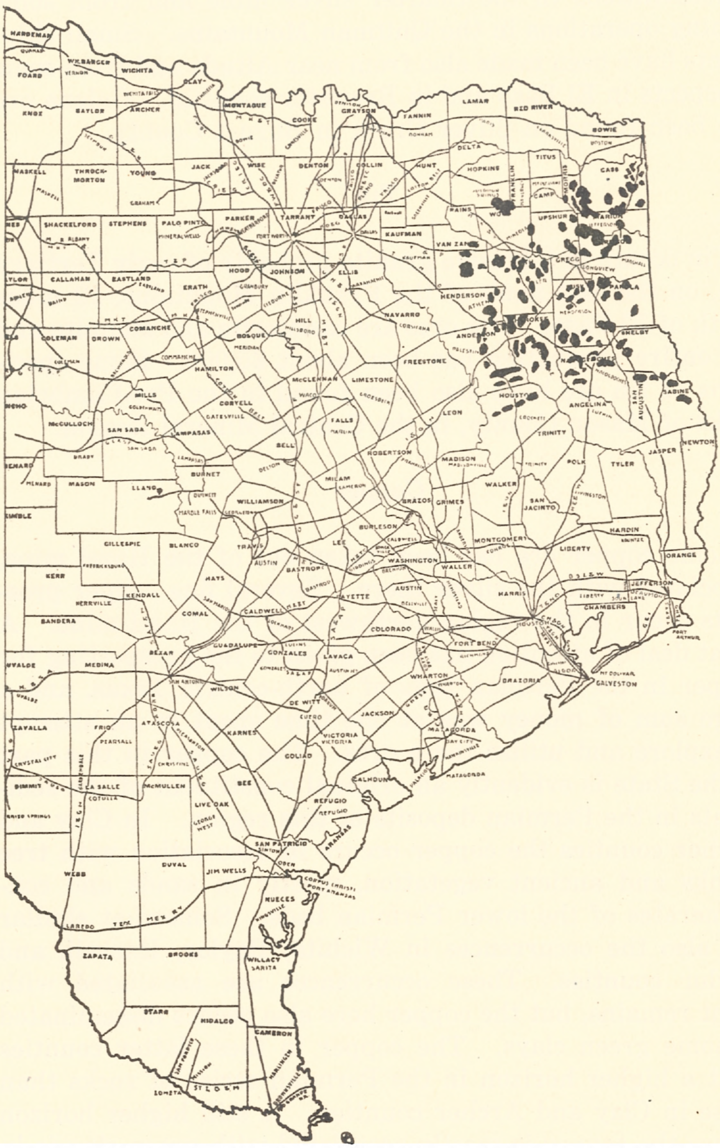

Figure 4.—Map showing known localities of iron ore in east and central Texas. Ore indicated by black.

concentrations in the Shafter silver mine and from some mining operations in the Quitman Mountains. Small shipments have been made also from near Altuda and from some prospects in El Paso and in Brewster counties. Galena ore has been found on Silver Creek in Burnet County.

Tin

Tin occurs in intrusive granite probably of early Tertiary age, on the east flank of the Franklin Mountains, 12 miles north of El Paso. The ores are cassiterite and stannite and the entire production has been about $5,000. Some specimens of tin ore have also been found in the Pre-Cambrian rocks of Mason County, in the Central Mineral Region.

Copper

Some copper ore has been taken out of the Hazel mine, associated with the silver there. Several fine copper prospects occur in the region northwest of the Hazel mine. A great deal of attention has been given to the prospecting for copper in the Permian beds of north-central Texas, and a large sum of money was at one time spent in an attempt to explore and utilize these ores. The copper in this part of the State is evidently an original constituent of the sediments in the Permian deposits of this region. In Clay and Archer counties the copper occurs in association with tree trunks and ancient vegetation, mostly in sands and conglomerates of the lower Permian beds. Somewhat similar are also the occurrences in Wichita, Baylor, Haskell, and Taylor counties. These occurrences are associated with plant remains, but the copper here also occurs disseminated in some green clays. The copper in these latter counties is at a higher horizon in the Permian series of rocks than those in Clay and Archer counties. A still higher horizon where the copper is mostly associated with green clay is in Foard, Knox, and Stonewall counties. The copper associated with plant remains and occurring in sands and conglomerates has so far proved too limited in quantity to be of any economic value whatever. If any of the green clays should be found to run sufficiently high in ore to be workable, these will be more likely to have sufficiently extensive distribution.

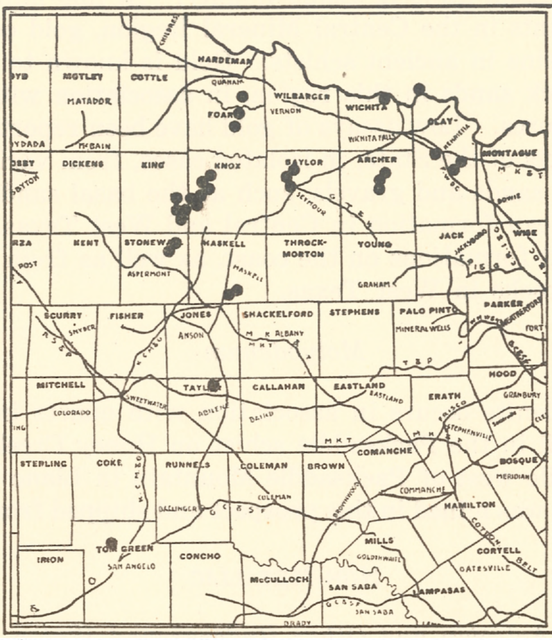

Figure 5.—Map showing the principal localities where copper has been prospected in the Permian in north Texas.

Zinc

Dry bone, or zinc carbonate, has been mined in some places in El Paso County. This ore occurs also at a point two miles west of Shafter in Presidio County. Zincblende as well as zinc carbonate occurs in the Buck zinc prospect, twelve miles north of Boracho. Some carloads of this ore were at one time shipped to El Paso. The ore occurs in cavernous places in the Permian limestones of the region.

Gold

It is believed that the total value of gold so far produced in Texas does not exceed $50,000. Some of this came from the old Heath mine in Llano County. In this mine, as at other points in the Central Mineral Region, gold occurs in quartz veins in ancient schists. Gold is known to exist in some black sands in this region, in association with silver and lead ores. Low assays of gold have been reported from other parts of the State, in isolated cases, from various ferruginous sands and gravels, such as the basal sands of the Comanchean formation in Central and West Texas, and in the recent formations on the coast, as well as from various igneous rocks in West Texas.

Molybdenum

Molybdenite occurs in association with quartz in a pegmatite sill in the Packsaddle schist on Honey Creek, about half a mile west of Packsaddle Mountain in Llano County. Some ore was mined in this prospect and shipped from Llano in 1918.

NON-METALLIC

Artesian and Other Underground Water

All underground water is derived from rainfall. It may be classified as non-artesian water and artesian water. The latter is water under hydrostatic pressure. Artesian water may flow when reached by the drill or it may escape in springs, or it may be non-flowing, rising to a greater or less depth in the well. Water in the deeper wells is more thoroughly filtered and usually more highly mineralized than the surface waters. The mineral matter is taken from the rocks by the water in its passage through them. Generally speaking, the farther the water travels underground, the more highly mineralized it becomes. Thus it is that some underground waters are usable when they are taken from near the area where they are derived from rainfall, while farther away from this area they are unfit for use.

Underground water is carried by porous beds like gravel, sand, conglomerate, sandstone, or limestone, in rocks containing caverns such as limestone, salt and gysum, and in rocks containing crevices mostly caused by the solvent power of water itself or through joints or faults, formed by forces which break and shatter the rocks. The largest supplies of underground water are found in the porous rocks, and these are the ones we will briefly consider.

For artesian water it is necessary to have (1) a continuous porous bed of rock which has a higher elevation in the region of its outcrop or catchment area than in a region where it is tapped by a well or spring; and (2) an impervious bed overlying the porous, saturated, water-bearing bed so as to prevent the upward escape of the water.

The level in the ground in which a well has a permanent supply of water is called the ground-water level. The ground-water level is the upper limit of the zone in which the openings in the rocks are saturated or full of water. The ground-water level is constantly fluctuating, rising during the rainy season and sinking during times of drought. In hilly countries of fairly abundant or great rainfall, the ground-water level is deeper beneath the surface under the hills, but higher in absolute altitude than it is underneath the valley, where it is nearer the surface. To this rule are two important exceptions. When the top of the hill is covered with sand and gravel which underlies impervious clays of the valleys, as in certain places in east Texas, the ground-water will be more abundant and found at lesser depths beneath the hills than in the valleys. Often also there are springs on the hillsides at the contact of the porous sands and gravels, above, with the impervious clays below. The impervious clays check the downward movement of the ground-water by percolation and hence it is forced to flow out at the surface in springs and caves or seepages. Another exception to the general rule occurs in the case of a stream flowing through a porous bed in an arid country, as in Trans-Pecos Texas, and contributing to the underground supply by seepage. In this case the ground-water level is both closer to the surface and higher in absolute elevation underneath the stream level than underneath the neighboring highlands.

Underground water is only stagnant or at an absolute standstill when it is confined in a porous bed, cavity, or crevice in the midst of non-porous rocks, or when it strongly adheres to the surface of the rocks or of the particles which compose the rocks. Ordinarily, underground water has a

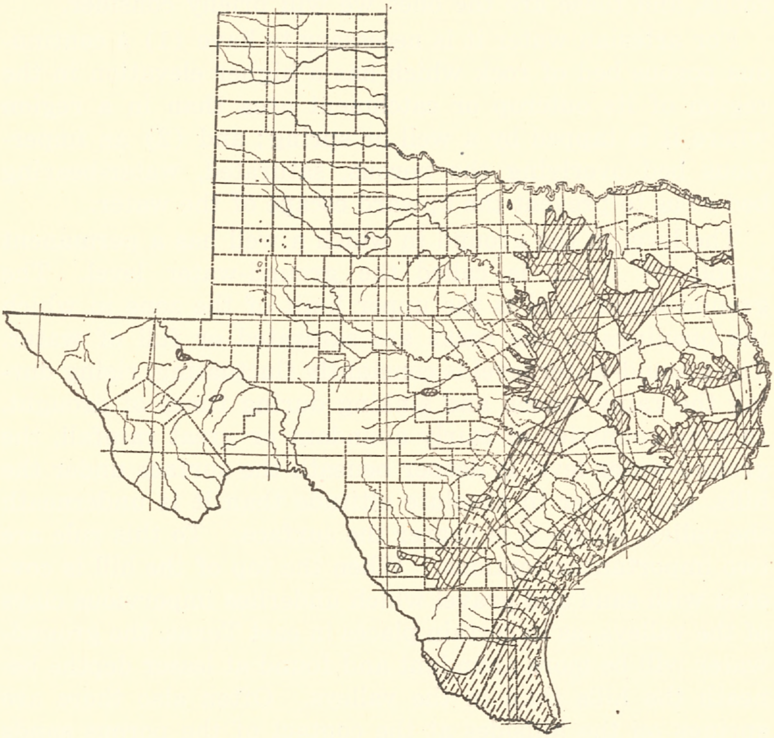

Figure 6.—Sketch map showing the principal known areas where artesian flows have been developed in Texas. Broken lines indicate prospective artesian areas.

slow, but definite and continuous movement through the rock, and it is always moving from a higher level to a lower. In a region of heavy rainfall, the underground water is moving from a region of higher elevation underneath the hills to a lower elevation in the valleys, and is always seeking, just like the waters of surface streams, lower and lower levels until it reaches the ocean.

Clay is classed as an impervious material because it will not yield an appreciable supply of water. Clays, however, absorb great quantities of water because they have a large amount of pore space, but the pores are so small that the clay holds the water tenaciously.

The main water-bearing rocks are gravels, sands, conglomerates, sandstones, volcanic tuff, and limestones. The most impervious rocks are clays, clayey marls, shales, and massive, compact, uncracked and unjointed, igneous rocks. Sandstones and limestones, moreover, may be so cemented into a dense rock that they carry little or no available water.

Some beds are such ready carriers of water that they yield no supply in the regions of their outcrop. The water from them escapes to other regions. Conspicuous examples of this are the Edwards limestone of the Edwards Plateau and Carmen Range, the jointed and fissured rocks of the Davis Mountains, the Guadalupian limestone in the Glass and Guadalupe Mountains, the Hueco limestone in the Diablo Plateau and Hueco Mountains, and many of the sand and sandstone formations, such as the Trinity, Woodbine, or Yegua. A sandy or gravelly soil so readily permits the passage of water through it that sufficient moisture is not retained in the overlying soils for the growth of crops.

The water which so readily soaks into formations like those above, either escapes to the surface again in the form of springs in other and it may be in far distant localities, or else it is stored up in porous strata which, when tapped by the drill, yield more or less abundant supplies.

There are two great artesian areas in Texas. One is the great geosyncline of the Llano Estacado, which lies east of the eastern Front Range of the mountains. The other is the great gulfward dipping monocline of the Edwards Plateau, Grand Prairie and Gulf Coastal Plain.

The rocks in the Llano Estacado geosyncline are the Anthracolitic. The rocks in the Gulf Coastal Plain monocline are Comanchean, Upper Cretaceous, Eocene, Oligocene(?), Miocene, Pliocene, and Pleistocene. In both artesian basins the escape of nearly all the water is prevented. The first proof of this is that the amount of mineral matter in the waters increases gradually as the distance from the outcrop of the water-bearing rock increases. If the artesian waters were free to escape from the beds in which they are confined, most of the mineral matter contained in the same beds would long ago have been removed, and there would also be a loss in the hydraulic head of the confined waters much greater than actually proves to be the case. The loss of hydraulic head that does occur is caused by adhesion of the water to the particles of the rock and the friction of flow through the rock. Artesian water, however, does escape to the surface by natural means in the line of artesian springs along the Balcones fault from northeast of Austin to and beyond Del Rio and the Rio Grande, and also in the artesian springs breaking through the Comanchean limestone at or near Toyahvale, Reeves County, and near Fort Stockton, Pecos County. Waters like these which flow through limestone rocks are characterized by having calcium carbonate as their ingredient, generally in high percentage.

Very little of the deep artesian water in the Llano Estacado syncline is fit for use because of its high content of mineral matter. The best quality of water is found about the outer edges of the basin in the rocks of the Triassic and Comanchean ages. Towards the center of the basin the later Permian rocks, containing large quantities of salt and gypsum, increase in thickness and the waters they contain also increase their percentage of mineral matter.

In the Gulf Coastal Plain the water in the porous beds is ponded and its escape prevented for two principal reasons: (1) as the Gulf is approached the sandy beds change to non-porous clays, as is to be expected in the deposition of coastal plain sediments; and (2) the porous beds are overlain by impervious clays and shales which prevent the upward escape of the imprisoned waters. There is considerable usable water in the Gulf Coastal Plain artesian area, both because the rainfall is greater and because there are more artesian horizons. The water in some horizons is much better than in others, because some water-bearing beds have less content of soluble minerals than do others. But any artesian water in this region traced far enough from its area of outcrop on the north or west towards the Gulf on the south or east, gradually becomes more or less mineralized until finally it becomes unfit for use. The chief horizons of artesian water in the Gulf Coastal Plain are the following: Trinity, Glenrose, Paluxy, Fredericksburg, and Buda of the Comanchean; Woodbine, the Blossom sand and the Nacatosh sand of the Upper Cretaceous; the Wilcox, the Queen City, the Carrizo, the Mt. Selman, the Lower Cook Mountain, the Yegua, and the Fayette of the Eocene; and the Catahoula of the Oligocene, the Oakville of the Miocene, and the Lafayette of the late Pliocene (?) or early Pleistocene in the Tertiary, and the Pleistocene. Deussen has recognized five principal artesian systems: the Lower Eocene, the Yegua, the Catahoula, the DeWitt, and the Coast Prairie systems. In the Cretaceous the most important artesian basin is the Trinity. This is the basal sand of the Comanchean, which supplies deep water in the Fort Worth, Dallas, Corsicana, Waco, Austin and other regions. The best water to be found in any of the Tertiary formations is that in the Lafayette. This formation is almost entirely made of sand and gravel, with a very small percentage of soluble mineral matter. The artesian waters in the western and drier portions of the Gulf Coastal Plain carry a higher mineral content than those in the eastern region. A small artesian basin is found in the Upper Cambrian Hickory sandstone of Mason County.

Ground or surface water which lies close enough to the surface to be possibly profitably pumped for irrigation purposes is found in the Pleistocene and Recent deposits in the valleys of the Red and other rivers, in the Seymour formation of Wilbarger, Hardeman, Foard, Knox, Baylor, Haskell, Throckmorton and other counties, in the later Cenozoic deposits on the Llano Estacado in Deaf Smith, Swisher, Hale, Floyd, Llano, Lubbock, Howard, and Midland, and possibly other counties, and in Pleistocene and Recent deposits in the Pecos Valley in Reeves and Pecos counties.

In most, if not all, of these places the ground-water level is held up by underlying impervious clays preventing farther downward movement of the water.

In the mountain region of Trans-Pecos Texas underground water is scarce, largely because there are so many porous limestones and volcanic lavas and tuffs which serve to rapidly carry away the water derived from the rainfall, scanty at its best. When the porous rocks are underlain by non-porous rocks, springs sometimes are found at the contact between the two. Springs are especially abundant in the Davis Mountains and the water there is of good quality. In the dèbris-filled areas between the mountains, water conditions are very uncertain, as regards quality, quantity and depth. In places the water level may be a thousand or more feet beneath the surface, and the water when found may be unfit for use.

From what has already been said it is apparent that mineral waters are very abundant in Texas. Mineral waters with a total value of several millions of dollars have been sold from the following counties: Bexar, Bowie, Callahan, Denton, Eastland, Erath, Falls, Galveston, Grayson, Gregg, Harrison, Hill, Hopkins, Kaufman, Lamar, Lampasas, Lavaca, Nacogdoches, Palo Pinto, Robertson, Smith, Titus, Williamson, and Wilson. There are hot springs in Brewster, El Paso and Presidio counties. Numerous sulphur springs occur, especially in eastern and southern Texas.

Oil and Gas

Originally all sedimentary rocks have no doubt contained more or less bituminous material from which oil, gas, ammonia and sulphur compounds might be derived. In all ages sedimentary rocks have been laid down in waters where animals and plants have lived. Seas, lakes, and rivers have existed on the earth's surface as far back as the record of sedimentation extends. There is more or less clear evidence of the presence of living things in all such waters of the past. Sand has usually been deposited at a comparatively rapid rate. For this reason, and also for the reason that sand is laid down by stronger currents than other sediments the original bituminous content of organic matter in sands and sandstones is relatively small, except in places where plants were flourishing and made deposits of peat. Clays and marls are deposited in more quiet waters, especially in the shallow border regions of the sea. In such waters, animal life and plant life usually flourish, and thus we find organic material to be more abundant in these deposits. The same may be said of such deep sea deposits as oozes or muds. Rocks formed from these nearly always contain a sufficient amount of organic material to be easily detected, when subjected to heat. It has been estimated that the bituminous material present in the upper 4,000 feet of the sedimentary rocks in the western part of Texas is sufficient in quantity to cover the ground with a layer at least one foot in thickness.

Oil and gas are derived from the partial decomposition of organic matter. The greater part probably comes from plants, although when accompanied by notable amounts of nitrogeous matter it is likely that they are formed at least partially from animal matter. Oil and gas originate in valuable quantities only in sedimentary rocks—almost never in igneous and metamorphic rocks. In the very few instances in which they are found in igneous or metamorphic rocks, they have in all probability first formed in sedimentary rocks and later migrated into adjoining igneous or metamorphic rocks.

Oil and gas are as a rule found only in rocks of purely marine origin or in rocks deposited in a river delta, or in the littoral deposit along the shore line of a sea. The main reason for this is that organic matter must be quickly sealed in impervious matter so as to prevent its total decay or destruction. Most of the oil and gas seems to have originated in the beds of shale or clay or clayey calcareous marls or limestones. Clayey material has the property of absorbing the oil material as well as being impervious to its passage, thereby preventing its escape and destruction during the time it is being formed. It is true that most of the oil and gas is found in beds of sand and porous limestone but it has probably migrated into the more porous beds at a later time than its formation. Furthermore, it is necessary for it to lodge in a porous bed in order to yield a valuable supply.

Consequently there is not much hope of ever getting oil or gas in Texas in the sediments deposited upon the surface of the dry land and such as the Cenozoic deposits covering the Llano Estacado and the Toyah Basin or in the Triassic deposits underlying the Staked Plains. The Red Bed sediments of north-central Texas and underlying the Toyah Basin cannot be expected to yield oil except on those rare instances when the oil has migrated into them from underlying formations. The lower Red Beds were sediments laid down upon the land; the upper Red Beds were laid down under arid conditions unfavorable to plant and animal life. Of course there is nothing to prevent oil being found underneath such sediments as these, provided other necessary conditions are favorable.

In past ages bituminous material originally imbedded in this way has been undergoing an exceedingly slow underground distillation. This has resulted in the driving away of the bituminous material from the oldest of the sedimentary rocks. The heat and pressure have been sufficient to change the original deposits from a truly clastic state to a more or less perfectly crystalline or metamorphic condition. All the rocks of Pre-Cambrian age have been thus changed. In these sediments no oil can be expected.

Owing to the natural underground distillation which has been in progress continuously in the past, it will readily be understood that wherever strata of sand or other porous rocks alternates with bituminous shales or limestones, the liquid and gaseous contents produced will be apt to escape from the shales and to accumulate in more porous strata. If we also consider that most rock and most sediments have at all times been more or less saturated by water under hydrostatic pressure, it will be readily understood that this water, being heavier than the oil or gas, has tended to drive the lighter bituminous product upward. Oil will float on water. Thus it happens that whenever porous strata run

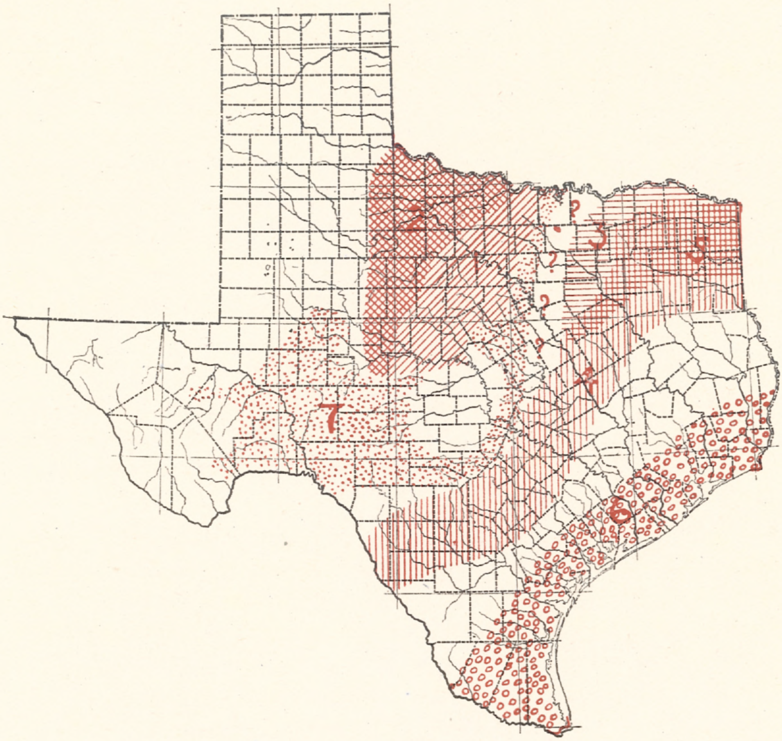

Plate 1—Sketch map showing belts where known oil-bearing horizons lie at suitable depths for exploration.

1—A belt underlain by the horizon of the lower sands of the Pennsylvanian.

2—A belt underlain by the horizons of the lower sands of the Pennsylvanian and also by the horizon of the sands in or near the Cisco.

3—A belt underlain by the horizon of the Woodbine sand.

4—A belt underlain by the horizon of the Corsicana sand in the lower part of the Taylor marl.

5—A belt underlain by the horizons of the Woodbine, the Corsicana, and in part of the Nacatosh sands.

6—The belt of the coastal salt dome oil fields.

7—A belt where the Pennsylvanian, and possibly in part the Permian, underlies the Comanchean, at depths varying from 0 to 1800 feet below the surface.

for any length at a slant, oil and gaseous contents are apt to accumulate in the upper part and at the highest point of such porous layers. Or they may escape at the surface where such strata outcrop, and leave, in places, solid residues of asphalt. This is sometimes found in crevices in such outcropping porous rocks.

Few sedimentary rocks at present occupy the same position that they originally had. They have been tilted, folded, and broken more or less. This tilting and folding has been very different in degree for different parts of the earth. In the mountain ranges in the western part of this State many of the formations stand at a high angle. There have been vertical movements involving many thousands of feet. Conditions have been like this also in the Central Mineral Region and in the belt formed by the Balcones escarpment. The rest of the State which is east of the Pecos and Rio Grande rivers has been subjected to much less disturbance. In regions where the disturbances have been great, the escape of the bituminous ingredient has proceeded at a rapid rate. The general experience is that where strong folding occurred as far back as before the Mesozoic age, the bitumens have had time to escape. The oil fields of Pennsylvania, West Virginia and Ohio are not in the strongly folded part of the Appalachian Mountains, but on the west side, where the folds are more gentle.

From all the above it will be understood that there are four conditions essential for a productive oil or gas field. These are: (1) the presence of a large body of bituminous rock yielding a source for the oil and gas; (2) structural conditions favorable for accumulation in sufficient quantities to be profitable; (3) storage within reach of the drill, in beds of sufficient porosity to yield a profitable supply; (4) the presence of a non-porous cover on the oil or gas-bearing horizon to prevent the escape of the oil and gas to the surface. The following structures are favorable for the accumulation of oil and gas: (1) anticlinal structure and, very rarely, synclinal structure; (2) dome structure; (3) sealed faults; (4) joint cracks; (5) lenticular porous beds occurring in non-porous rocks—accumulations due to thinning or change in texture of the "sand" in some direction; (6) terrace structures, or local changes in the general dip of the rocks.

There can be no doubt that some one of the above structures of the sedimentary beds is one of the most necessary conditions for the accumulation of oil and gas in profitable quantities. The original anticlinal theory explains most of the oil and gas fields of the world, and probably more than all other conditions combined. This theory accounts for the accumulation of pools of oil and gas at certain favorable places by the difference in weight of gas, oil and salt water, where the water is under hydrotatic (still) condition. The water is under artesian pressure and is in a stagnant condition because its escape is prevented.

Profitable supplies of oil and gas have been found in this State only in certain parts of the Pennsylvanian, in the Cretaceous sediments, in the Tertiary sediments and in one instance (Thrall field) in an altered igneous rock of Cretaceous age. (See figure 7 and Plate I.)

Oil in the Pennsylvanian

In the Pennsylvanian there are several productive oil horizons; some sands in the Cisco, some in the Canyon, and some in the Strawn. The oil and gas at from 750 to 1,000 feet in the Electra and the Petrolia fields come from sands in the upper part of the Cisco or immediately above this formation. Some shallow oil at Lohn in McCulloch County is from a sand in the same formation. The oil and gas in the Trickham field and some shallow oil at Brownwood, is from the Canyon or from immediately below this formation. The deep oils in the Electra and Petrolia fields are believed to come from either the lower part of the Cisco formation or else from the underlying Canyon. At Moran and at Strawn the oil-bearing sands belong to the Strawn formation. The Bend formation, which contains some rocks that are highly bituminous, is the source of some oil which has been obtained at a depth of about 2,000 feet near Brownwood in Brown County and it is the source of the deep oil now being developed at Ranger in Eastland and other counties farther north.

Oil in the Cretaceous

In the Upper Cretaceous two or three horizons are productively oil-bearing in this State. The Woodbine, which contains the productive sand in the Caddo field in Louisiana, extends under a large area in the northeast part of Texas and has proved productive in Marion County. The sands which yield the oil at Corsicana and Powell in Navarro County and at Somerset in Bexar County are in the Taylor marl. The altered igneous rock and overlying shaly sand which yield the oil in the Thrall field occur at about the same stratigraphic level as the main sand in the Corsicana field. In the Alta Vista field and in the Mission field near San Antonio, the oil comes from the Austin chalk. The gas reservoir at Mexia is in a sand which has been called the Nacatosh sand, and which is to be regarded as being either in the base of the Navarro formation or in the upper part of the underlying Taylor marl, according to where the ill-defined limit between these two formations is placed.

Oil on the Gulf Coast

On the Gulf Coast oil occurs in so-called salt dome structures. Under these fields there are domes of salt that extend to unknown depths and reach from less than one to three miles horizontally. These structures differ markedly from those containing oil in inland pools in this State, and elsewhere in America. The latter we call strata oil pools to distinguish them from the salt dome pools of the coast. Compared with the inland fields, the salt dome pools are smaller in extent, and their production is relatively much greater for the size of the field.

The salt dome oil fields have produced most of our great gushers. The gusher production usually lasts only two or three years.

The salt dome is overlain by a cap of gypsum and dolomite. The dolomite is usually referred to as the "cap rock."

Neither of these formations extends much beyond the salt in the domes. As they have no equivalent in the series of the original sediments of the coast country, they have evidently been built up in their present place at the same time with the salt dome or later than this. The dolomite is for the most part very coarsely crystalline. Sulphur and barite are frequently associated with the gypsum or anhydrite which underlies the cap rock.

The first production of the salt dome fields has mostly been from the cap rock overlying the salt. A subsequent production in these fields has been in several cases secured from below the clay beds which reach up over the salt domes on all sides. This is known as the deep production, to distinguish it from the "shallow," or "cap rock" production in the center of the field. It is believed by some that the oil in the Gulf Coastal salt domes has originated from the Fleming formation, which usually is involved in the uplift of these structures.

The salt dome fields are as yet but imperfectly understood. In Texas alone it is represented that some thirty-four such structures have been discovered. A few of these form a group in the northeast part of the State where they seem to have been mostly eroded away. What is left of them here appears to be their basal part only. Such are the Grand Saline and the Brooks Saline. The largest group of salt dome structures is scattered over Jefferson, Hardin, Liberty, Harris, Galveston, Brazoria, and Matagorda counties. A third group is indicated for San Patricio, Duval, Brooks, and adjacent counties.

All of these known salt domes are not productive. More than half of them are as yet barren, but all are essentially of the same kind and have evidently been produced by more or less identical conditions and geological forces. The growth or the rise of the salt in the domes has been so slow that the erosion of the surface of the land appears in most cases to have kept pace with the slow process of elevation. It is only in a few cases that the rise of the ground has exceeded erosion, so that the surface of the ground over the

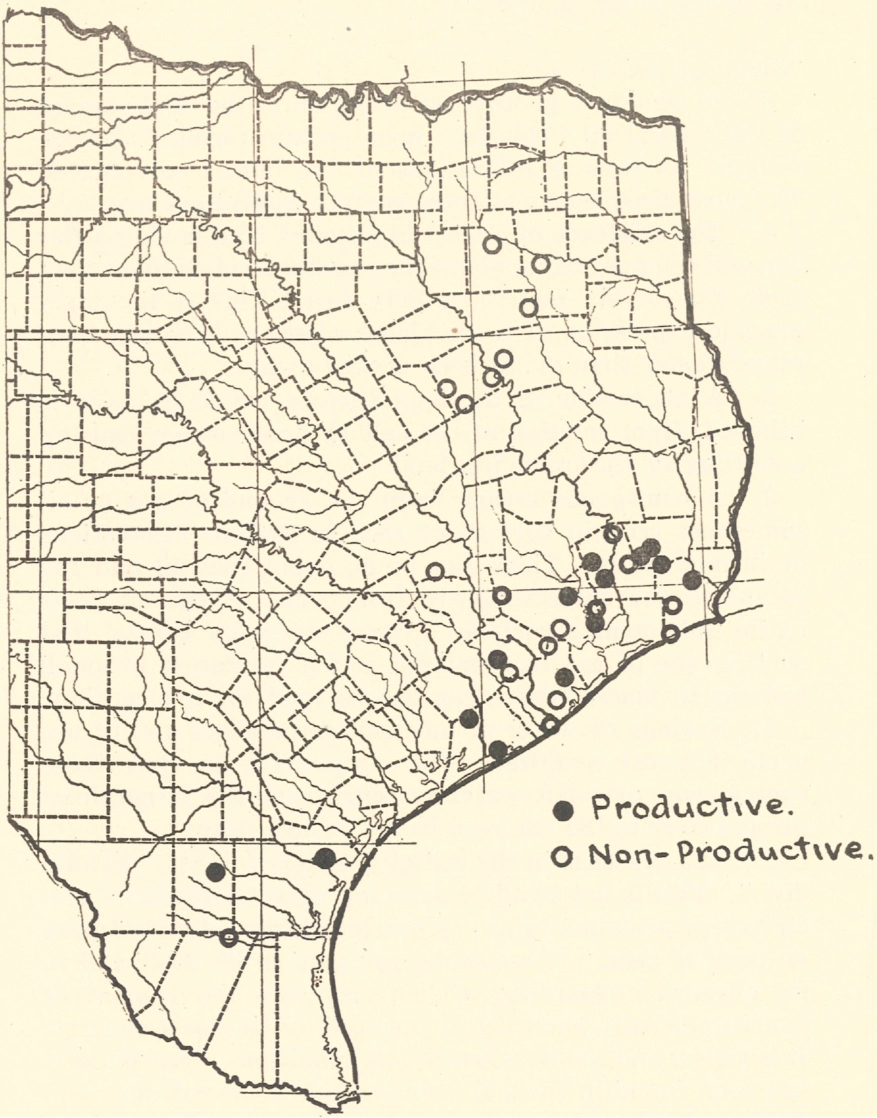

Figure 7.—Map showing locations of known salt dome structures on the Gulf Coastal Plain.

salt domes now is slightly higher than the flat surface of the surrounding country.

"Surface Indications"

Those who have given most attention to the development of the coastal oil fields look upon certain physical characteristics as surface indications of the buried salt domes. The most conspicuous of these surface indications are:

1. The existence of a tract of elevated land having a flat dome-like shape, rising above the general level no more than from five or six feet to seventy feet. This is the topographic expression of a salt dome where a dome has been raised faster than it has been eroded away.

2. A depression of the land surface resulting, as it is believed, from solution of the salt by fresh water, causing a settling of the overlying land.

3. A continuous escape from the ground of gas or oil sometimes seen in springs or seen in shallow excavations or in mud pools. There can be no doubt that oil and gas escape to the surface slowly from some of the oil pools in the salt dome structures. Some observers believe that such escape of gas has resulted in the formation of small hillocks in places where gas has escaped for a long time.

4. Springs of water of unusual temperature and of unusual mineral qualities. The supposition is that these springs are artesian water coming from the mineralized ground close to the cap rock in the buried dome.

5. The presence in the soil of a material called "paraffin dirt." This is not at all paraffin but more resembles a precipitate of peaty material. When burnt this substance gives an odor of peat. It resembles art gum in its color and in its physical appearance when it contains the amount of moisture usually present in the subsoil of the coast country. It is yellow and elastic when in this condition. Paraffin dirt has been found in the soil over several of the salt dome oil fields and it has been suggested that it may be the result of some chemical reaction between escaping gases and vegetable materials present in the soil.

6. A physiographic surface indication to be seen in the

arrangement of the drainage. Owing to the continuous rising of the central region of a salt dome, drainage lines are apt to be found radiating from the center of the domes, so as to cause them to be located under a small watershed, as it were. This arrangement of the drainage may persist after the dome itself has disappeared entirely.

Minor Oil-bearing Formations

A number of other Texas formations have yielded shows of oil or gas, either in wells or on their outcrops. The Ordovician of the Marathon country is one of these. In that vicinity the rocks have possibly been too greatly folded and faulted to yield profitable supplies. The Ordovician might possibly yield oil at some other locality in West Texas where covered by later formations, and where the folding has not been intense. The Delaware Mountain formation of the Guadalupe Permian of Trans-Pecos Texas is also quite bituminous at places on its outcrop and is probably the formation which has yielded some shows of oil in deep borings in the vicinity of Toyah. Farther east in north-central Texas, the portion of the Lower Permian known as the Albany has also yielded some showings. Small showings of oil, gas and asphalt have been noted in the Comanchean, as north of South Bosque and in some shallow borings near Toyah. The oil and gas in this latter region may have migrated from the underlying formation, particularly the Pennsylvanian. The Eagle Ford formation of the Upper Cretaceous has yielded numerous showings.

The Wilcox Eocene in its marine phase near the southeastern region of its outcrop in the vicinity of the Sabine River has yielded small quantities of both oil and gas. The lignite-bearing portion of the Wilcox, which formation is also known as the Lignitic or Sabine, does not appear very favorable for oil but may yield gas. The Cook Mountain Eocene has yielded a small production at Oil City, Nacogdoches County, and at Crowther, McMullen County. The Yegua Eocene yields gas at Gonzales, Aguilares, and in Zapata County on the Jennings ranch. Some small seepages of asphalt have been found in the Jackson (formerly known as the Fayette) Eocene, in the southeastern Gulf Coastal Plain.

It is apparent, therefore, that only where one of these petroliferous formations can be reached by the drill in places where the structure, degree of porosity, and an adequate impervious cover afford favorable conditions are the chances

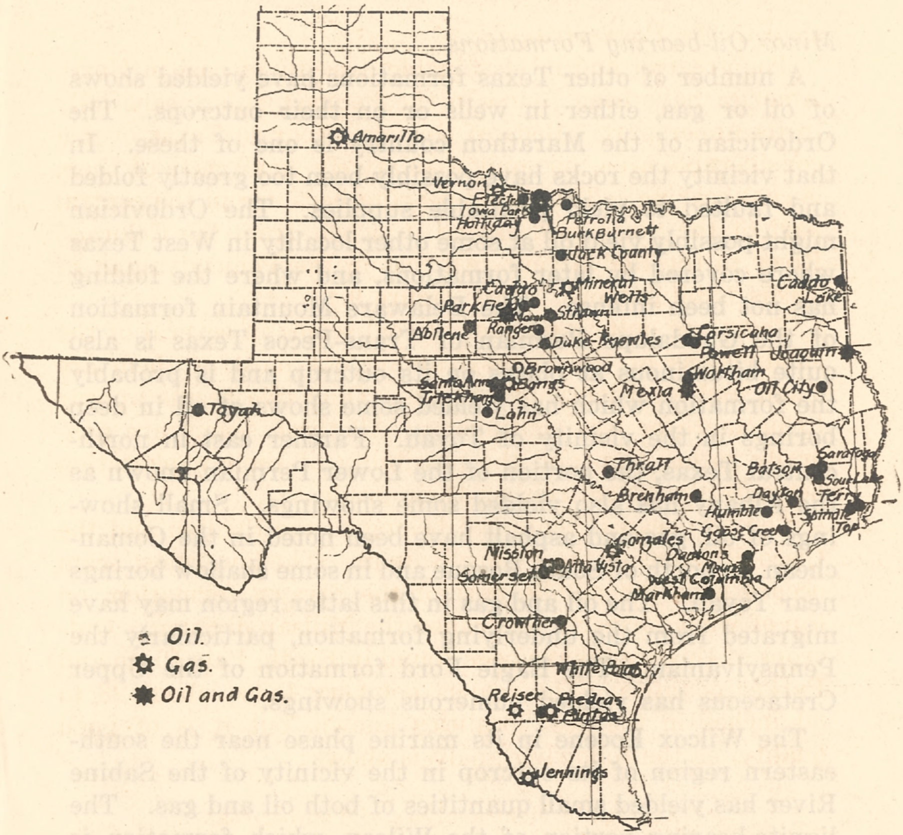

Figure 8.—Sketch map showing the oil and gas fields in Texas.

favorable for making producing wells. It may be that some of the formations not now known to be bituminous may be found to be oil- or gas-bearing in the future in places where they are covered by other formations. But we have no really safe means of predicting such localities at present. The locations of the producing oil and gas fields of the State are shown on the accompanying sketch map which also indicates the areas in the State underlain by the principal known productive formations.

Coal and Lignite

Coal in the Pennsylvanian

The greatest and most valuable deposits of coal in North America have been found in the Pennsylvanian, especially in its upper part. Beds of this age occur in Texas over a considerable area, but only a relatively small part of them is coal-bearing. These coal-bearing beds are in the central part of the State, and extend in a belt from the Colorado River to the Red River. All coal in the Pennsylvanian of Texas is bituminous. (See figure 9.)

There are quite a number of coal seams in several of the subdivisions of the Pennsylvanian, but most of them are small and local lenticular bodies. Only two seams appear to be more or less continuous. All these seams are generally rather thin and the possibility of their exploitation depends almost entirely on their grade.

The two seams mentioned belong to the Strawn and the Cisco divisions of the Pennsylvanian. The lowermost seam occurs near the middle part of the Strawn formation, on top of what formerly was called the Millsap division. Outcrops of this seam have been found in Erath, Palo Pinto and Parker counties. The coal is not very thick, about 28 to 30 inches in the best localities known, but it is of good quality, as the following analysis shows:

Average of eight analyses of Thurber coal.

	Per cent
Moisture	3.30
Volatile combustible matter	34.11
Fixed carbon	49.88
Ash	12.71
Sulphur	1.81
B. t. u. per pound	11,871

More than half of the bituminous coal produced in this State comes from Erath County. The principal mines exist in the vicinity of Thurber. Other important mines are near Strawn, Palo Pinto County. An average analysis of the coal of this locality is as follows:

	Per cent
Moisture	2.51
Volatile combustible matter	35.68
Fixed carbon	46.34
Ash	15.47
Sulphur	3.08
B. t. u. per pound	11,778

In Parker County no coal is being mined at the present day. Several coal seams have been found farther north in Wise County, and it was thought that one of them belonged to the Strawn division. Later investigations have made it probable that those seams belong to the Canyon division. This coal is being mined at Bridgeport. An average of six analyses gives the following result:

	Per cent
Moisture	9.81
Volatile combustible matter	33.06
Fixed carbon	48.66
Ash	12.47
Sulphur	2.03
B. t. u. per pound	10,396

The higher one of the two more important coal seams occurs in the upper part of the Cisco division. While the Strawn coal disappears north of the Colorado River, the Cisco coal is found much farther south in Coleman County, where the principal seam has been called the Bull Creek coal seam, by N. F. Drake. From there the outcrop of the seam extends through Brown, Eastland, Stephens, Young and Jack counties to Montague County. At the present time this coal seam is being mined only in Eastland and Young counties. The most important mines are near Newcastle, in Young County. The character of the coal from that locality is shown by the following average of two analyses:

	Per cent
Moisture	9.00
Volatile combustible matter	35.79
Fixed carbon	39.08
Ash	16.13
Sulphur	2.88
B. t. u. per pound	9,601

The coal seams of the Cisco formation are also thin. The most important one shows a maximum thickness of 24 to 35 inches. Frequently several smaller seams are found near the principal one, but separated from it by beds of shale.

Coal in the Upper Cretaceous

The only place where this coal, which is a light bituminous coal, has been successfully mined in Texas is near Eagle Pass. The coal-bearing formation has been called the Eagle Pass Series. It overlies the San Miguel and underlies the Escondido beds. The coal lies in two or three beds separated by clay partings. Together the beds measure from three to five feet. The field probably does not extend beyond a half dozen miles east of the Rio Grande, and probably less than a dozen miles along the Texas boundary. Coal has been mined for over twenty years in this field, and the production has been considerable. Coal occurs in the Upper Cretaceous also in Brewster County, south and east of Terlingua, but in this region its thickness is less. The same is to be said of the Cretaceous coal once mined at San Carlos in Presidio County. This coal has also been found on the north side of Eagle Mountains.

The Cretaceous coal is lustrous brownish black and does not slack in the air. An average of several analyses of this coal is as below:

	Per cent
Moisture	2.2
Volatile combustible matter	38.8
Fixed carbon	43.9
Ash	14.9

Lignite

Lignite occurs in beds from less than one to a dozen feet thick in the Eocene Tertiary sediments. Localities of out-

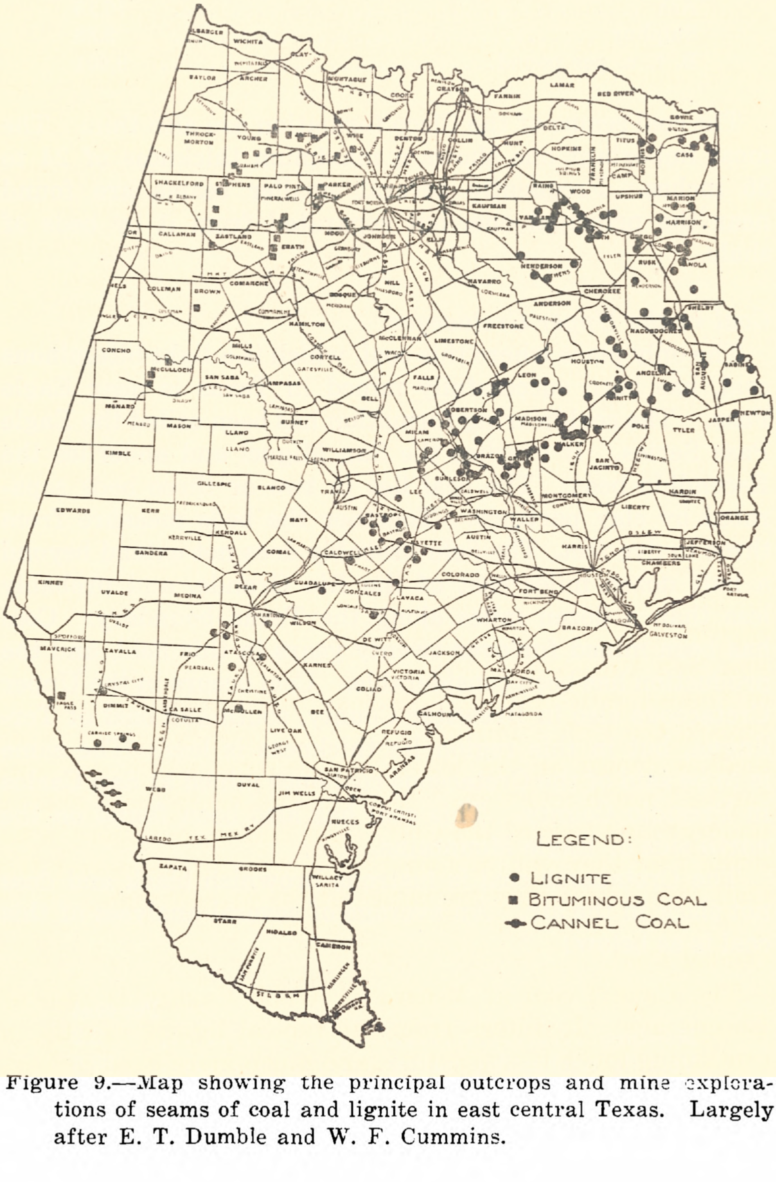

Figure 9.—Map showing the principal outcrops and mine explorations of seams of coal and lignite in east central Texas. Largely after E. T. Dumble and W. F. Cummins.

crops of lignite were more than twenty years ago compiled by E. T. Dumble, who made exhaustive studies of this Texas fuel. The lignite lies in the belt of outcrop of the Eocene sediments from the northeast corner of the State to Webb County on the Rio Grande. The thickness of the Eocene beds which contain the lignite probably approximates 1,500 feet. Two lignite-bearing zones have been distinguished. The lower one occurs in the next to the lowermost formation of the Texas Tertiary, known as the Wilcox. The lignite beds are lenticular and occur mostly throughout the lower two-thirds of the 800 to 1,000 feet of sediments of which this formation consists. This belt contains lignite in Zavalla, Medina, Bexar, Guadalupe, Caldwell, Bastrop, Milam, Robertson, Henderson, Leon, Van Zandt, Smith, Wood, Bowie, and other counties. It is sometimes referred to as the northern lignite belt. The upper lignite zone occurs in the Fayette, Jackson and Yegua formations which lie some 800 to 1,000 feet higher up than the Wilcox in the section of the Tertiary. As the dip is to the southeast the outcrops of lignite of this horizon roughly parallel those of the lower horizon in a belt farther south and east. Lignite in this belt has been observed in Gonzales, Fayette, Washington, Burleson, Grimes, Walker, Houston, Trinity, Angelina, San Augustine, Shelby, and some other counties. Both of these lignite-bearing horizons dip under later deposits toward the Gulf. Mining so far has been done mostly at shallow depths on the lower lignitic zone, which outcrops farthest north and west. How far the lignite beds extend underground toward the Gulf is not known, but there is no doubt that they will be found at greater depths nearer the Gulf than where they are mined at the present time.

Cannel Coal

The *Cannel* coal at Minera in Webb County is also of Eocene age. It differs from the typical lignite greatly in containing much less moisture, and much more fixed carbon. Averages of the composition of each of these two fuels are about as below:

Averages of analyses of Tertiary lignites and Cannel coal

	Typical lignite Per cent	Minera Cannel Per cent
Moisture	33.3	3.0
Volatile combustible matter	40.4	43.3
Fixed carbon	13.9	36.8
Ash	9.0	13.8

The production of lignite in Texas has steadily increased for the last twenty years, from 124,000 tons in 1895 to 1,100,000 tons in 1914. It is extensively used in stationary engines and also as domestic fuel. The Cannel coal from Webb County makes an excellent fuel for domestic use.

Sulphur

Sulphur occurs in beds of gypsum and shale in two formations: in the upper Permian of the Toyah Basin, of the Trans-Pecos region, and in the salt domes of the Gulf Coastal Plain. The chief present production is at Freeport, in Brazoria County and recently large production has been secured at Big Hill, in Matagorda County. Extensive explorations have proved enormous deposits of sulphur at Damon Mound and at Hoskins Mound in Brazoria County. In the Trans-Pecos region sulphur occurs at or near the surface in the Permian shales and limestones, in various places in Culberson County. Sulphur has also been found in some borings in Pecos County, 14 miles northeast from Fort Stockton. On the coast, the sulphur occurs in association with anhydrite underlying the cap rock of several salt domes. Production in the coast country has been rapidly developed during the last few years.

Salt

Salt in Texas is found in the Clear Fork and Double Mountain beds of the Permian and for years it was produced at Colorado City in Mitchell County. Salt also occurs in the salt domes of the Gulf Coastal Plain, but is now produced only from Grand Saline in Van Zandt County, and from the Palestine Saline in Anderson County. Formerly salines in Smith, Angelina, Crane and other counties westward were worked. The salines and the salt domes are at least for the most part in formations of Tertiary age. A number of salt lakes occur on the Staked Plains. A large amount of salt of recent origin occurs on the surface in the Salt Basin of El Paso County. More than $4,000,000 worth of salt has been produced in this State mostly in Colorado

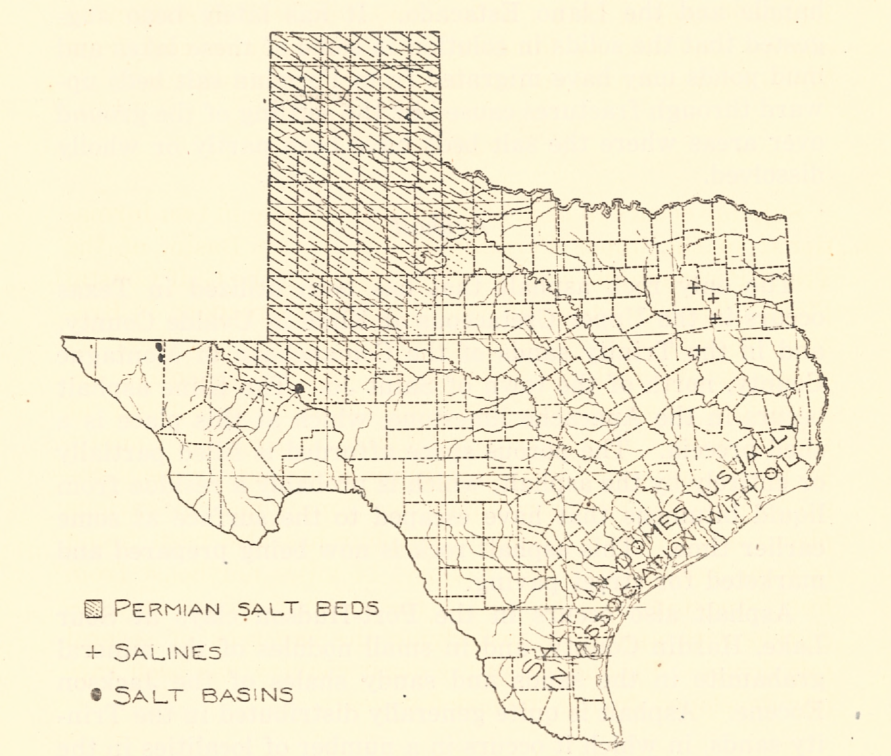

Figure 10.—Sketch map showing the principal areas and localities where underground salt beds and surface accumulations of salt occur in Texas.

City in Mitchell County. The salt industry would be capable of much greater expansion if salt were more in demand. There are in addition a great number of salt waters or brines in the State, mostly encountered in deep drillings. None of these has as yet been utilized.

Potash

Potash in the form of what appears to be carnolite has been found in cuttings through deep-lying salt beds in the Panhandle and enterprises are under way also for the utilization of potash in briny lakes in the region of the Panhandle and the Llano Estacado. It has lately been suggested that the solids in solution in some of these lakes and mud ponds may have migrated from Permian salt beds upward through fractures caused by the settling of the ground over areas where the salt beds have been partly or wholly dissolved.

Asphalt

The only rock asphalt that has been utilized in Texas occurs in the Upper Cretaceous at Kline in Uvalde County, and in the Trinity sands of the Comanchean in Montague County, north of the town of Saint Jo. The Kline asphalt occurs in the Anacacho limestone, which at this place is a shell breccia. The porous space afforded is filled partially or entirely by the asphalt, which is probably a residue from liquid bitumens that have escaped to the surface at some earlier time. This asphalt rock is now being prepared and marketed for street paving.

Asphalt also occurs in the Port-Hudson clays at Sour Lake, Hardin County, and in small nodules of the mineral grahamite in the sands and sandy shales of the Jackson Eocene. Asphalt is quite generally distributed in the Trinity sands, in which it occurs in a number of localities in the north part of the State.

Graphite

Graphite is common in the Packsaddle schist in which it occurs disseminated with the principal minerals of this rock in varying quantities known to run as high as twelve per cent. It has been observed that the graphite is most common near some limestones or marbles which occur in various parts of this schist.

A large mill has been erected and some graphite has been produced at a place two miles east of Niggerhead, on Clear Creek, and eight miles west and two miles north of Burnet, in Burnet County. Another mill has been erected at the old Heath gold mine, about five miles east of Llano. These schists have a considerable distribution in Llano and Mason counties and extend into Blanco and Gillespie counties, where graphite is also known to occur.

Talc and Serpentine

Talc is found in the Packsaddle schist and other Pre-Cambrian formations in many places in the Central Mineral Region. It is frequently associated with serpentine. A large body of the latter rock has been explored on the Collins property about nine miles west of Llano in Llano County.

Celestite

Celestite, or strontium sulphate, is found filling cavities in the Glenrose limestone and marls of the Comanchean in Lampasas, Burnet, Williamson, and Travis counties. Very little of this mineral has been marketed from this State.

Mica

Some mica has been mined from a pegmatite in the Van Horn Mountains in Culberson County.

Gems and Precious Stones

Topaz has been found near Streeter and Katemcy in Mason County, in gravel of local origin and also in pegmatite occurring in granite. Pearls have been found in Caddo Lake and in the Llano and the Colorado rivers. Opal and agate occur in various places in Brewster County. Turquois, mostly as turquois matrix, occurs in the Carrizo formation, west of Van Horn in Culberson County, and jet, of poor grade, has been observed associated with Upper Cretaceous coal in Brewster and Presidio counties.

Rare Earths and Radio-active Minerals

The following rare-earth minerals are found at Barringer Hill, Llano County, in a Pre-Cambrian pegmatite: allanite, cyrtolite, fergusonite, gadolinite, gummite, mackintoshite, nivenite, polycrase, rowlandite, tengerite, thorogummite, and yttrialite. A number of these minerals are radio-active. The economic importance of the rare-earth minerals is due to their property of glowing or becoming incandescent upon being heated.

BUILDING MATERIALS

Clays

Clays of Texas of economic value may be confined in five groups: (1) buff-burning refractory and semi-refractory clays suitable for the manufacture of firebrick, stoneware, buff pressed brick, terra cotta, floor tiles, and art pottery; (2) common brick clays, for the manufacture of common brick, red pressed brick, drain tile and earthenware; (3) slip clays, easily fusible and forming a natural glaze; (4) kaolin, for the making of pottery; and (5) fullers earth for the decolorizing of oils, either mineral, vegetable or animal.

The value of the clay products of the State has already reached about fifty million dollars. The brick and other clay-products industries are destined to increase at a rapid rate in the future as lumber will become more costly and scarce, and people come to build more permanent structures. Two of the great advantages of clay products over wood in building construction are their superior durability, lessening much the costs of repairs and rebuilding; and their fireproof qualities.

It is a fortunate circumstance that the greatest abundance and variety of valuable clays occur in that eastern portion of Texas which seems destined to have always the bulk of the population and where building products of clay can most safely be used. Clay for adobe and the manufacture of

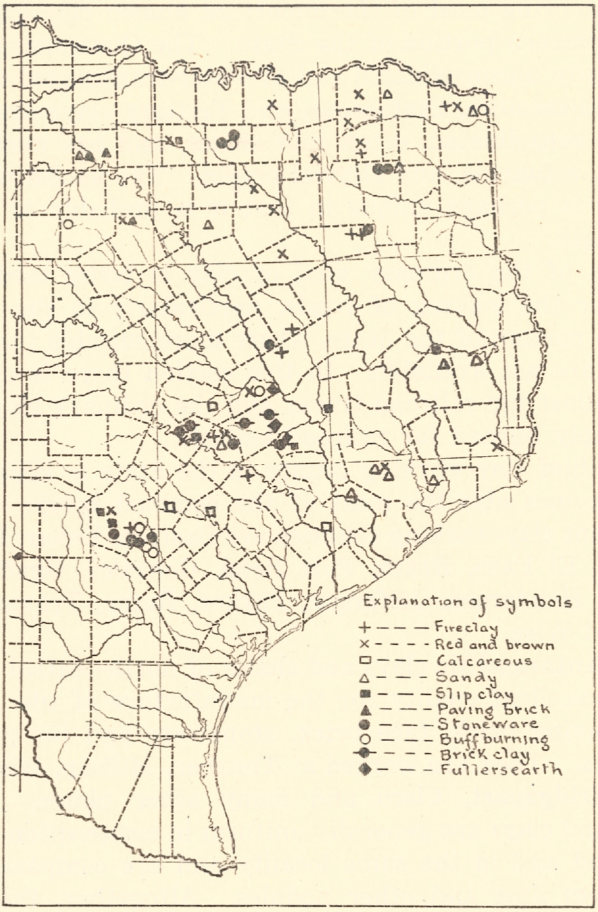

Figure 11.—Sketch map showing the principal known localities of clays worked in the east part of Texas. Adapted from Heinrich Ries.

common brick, especially that of the Quaternary age, is fairly abundant in the western portion of the State.

Nearly all the clays of economic value in Texas belong to four geologic groups: (1) the Anthracolitic (Pennsylvanian and Permian); (2) the Cretaceous; (3) the Tertiary; and (4) the Quaternary. The distribution of these groups can be seen from the geologic map. A sketch map is also given showing most of the important known clay localities in the eastern portion of the State. The Quaternary clays are mostly unconsolidated and of water-transported origin; the Anthracolitic, Cretaceous, and Tertiary clays are more or less consolidated, often into shales, and are mainly of marine, estuarine, and alluvial origin. The kaolin in Real County is perhaps unique in that it is probably of chemical origin.

Much of the ordinary kind of clay is being used with sand for the making of roads, particularly in the southeastern portion of the State, where more suitable road materials are not available. In this section there is also no rock ballast for railroad tracks and the ordinary clays can be cheaply burned for railroad ballast.

The chief clay-working county in the State is Ellis from which comes also the most of the common brick. Other important clay-working counties are Bastrop, Bexar, Bowie, Denton, El Paso, Erath, Fort Bend, Gonzales, Guadalupe. Harris, Henderson, Jefferson, Parker, Rains, Travis, Wilson, and Wise.

The Anthracolitic clays and shales of north-central Texas are of excellent quality for the manufacture of tile, sewer pipe, paving brick, face brick, stoneware and for glazing purposes. They are worked at Thurber, Millsap, Weatherford, Bridgeport, Cisco and many other places. These shales and clays are generally uniform in composition in the same bed and in the same locality and are comparatively free from lime and other nodules. Altogether, they are probably the best clays in the State for the manufacture of the more common clay products. They are located on the edge rather than in the midst of the most populous sections, but they have the advantage of being near coal, oil, or gas fields, which afford a readily available supply of fuel. Fire clays are found in connection with the coal beds and a very superior grade of paving brick is produced at Thurber.

The clays occurring in the Upper Cretaceous have so far been most extensively utilized owing to the fact that these clays occur in the most populous portion of the State. As a class, these clays are locally inferior in quality. They are apt to contain concretions of lime and of pyrite. Clays of the Woodbine formation have been utilized at Denton. In the counties of Dallas, Collin, McLennan, and Grayson, clays from the Eagle Ford formation have been quite extensively worked. Their bituminous character and their extreme toughness compels the manufacturer to mold them by the dry process, and the occurrence of gypsum and pyrite requires careful selection of material. The Taylor marl clays have long been utilized at Ferris and the Navarro beds have been used quite extensively at Taylor and at Ferris.

A very good grade of kaolin in probably large quantity occurs in the Edwards limestone about six miles west of Leakey, Real County. This locality is forty-five miles distant from a railroad and its development will be handicapped by the heavy freight rates to the centers of fine pottery and chinaware manufacture.

Among Tertiary clays those of the Eocene are most important. Of these the Wilcox formation affords the most valuable deposits, both in quality, abundance, and in nearness to the more populous sections. The clays of the Midway contain considerable lime, are quite sandy, and often contain crystals of gypsum. The clay beds near the base of the Wilcox are associated with beds of lignite, available for fuel. Beds of lignite are also interstratified with beds of shales, sometimes semi-refractory, and with non-refractory clays of excellent plasticity. A third type, worked at New Boston and Sulphur Springs, is a red-burning, tough, shaly clay. A fourth and more widely-distributed type is represented by lenticular deposits of grayish, highly plastic, refractory or semi-refractory clay, occurring throughout the entire lignitic belt and utilized in Bexar, Wilson, Limestone, Bastrop, Falls, Henderson, Smith, Wood, and Bowie counties. Clays of the Cook Mountain formation are worked at Rusk, Nacogdoches and Henderson. There are some clays of economic value in the Yegüa, Fayette, Frio, and Jackson formations, but these have been as yet little utilized.

Fullers earth occurs in the Corrigan formation and has been worked on a small scale in Washington County. It is now produced and extensively shipped from Bexar County.

Quaternary clays for the manufacture of common brick, for the making of sand-clay roads, and for the burning of railroad ballast are found in the Lafayette and Port Hudson-Columbia formations of the Gulf Coastal Plain, and in the Recent alluvial and wind deposits in many localities throughout the State.

Fuller's Earth

Fuller's earth has been prepared more or less experimentally from some deposits occurring in the Tertiary sediments in Burleson, Fayette, and other counties. It has been found very difficult to introduce a new product in the market. Recently a fuller's earth has been found in the Taylor marls in Bexar County. This is now prepared for the market and has extensively replaced imported fuller's earth from England and elsewhere. It occurs at a horizon somewhere between 150 and 200 feet above the Austin chalk. It is known that this is a horizon containing hydrated volcanic dust which is also an ingredient in the fuller's earth now prepared for the market. The horizon extends across the State and it is quite likely that other localities may be found where this earth will have the characteristics found in Bexar County and where it can be utilized.

This fuller's earth itself is light drab in color, when wet, and lighter drab when dry. It exhibits no bedding or other structures in the bank, and upon drying it cracks and joints in a very irregular manner. It is entirely free from grit and it is not plastic. It slacks when immersed in water, which it absorbs. The earth is prepared by first crushing and drying over a fire at the pit. It is then hauled to a mill and ground to a fine powder. This product is now marketed to packing houses and oil refineries. It is reported that it requires less pressure and less time to free the refined oil from this earth than is the case with the English product, and that it leaves less odor in the oil.

Lime

The rock which seems to be best suited for the manufacture of lime in Texas is in some layers in the Georgetown division of the Comanchean Series. The rock in these layers is somewhat porous and burns well, making a white lime of uniform character. The limestone burned in Bexar, Comal, Travis, Williamson, and Coryell counties is mostly from this horizon, which outcrops in various places along the Balcones escarpment. A notable character of this rock is its purity. An average of several analyses of the rock used for lime in these counties shows only a trifle more than one per cent of impurities. It is almost entirely a carbonate of lime. In the eastern part of the State limestone does not exist near the surface, except in very small amounts at a few places. West of the Balcones escarpment, good limestone is common, especially to the south. At El Paso lime is burned from Ordovician dolomite as well as from Comanchean limestone, which here also is very pure.

The annual production of lime in Texas is estimated at about 45,900 tons, valued at some $256,000.

Cement

Limestone in the Pennsylvanian and the older Paleozoic rocks in the Central Mineral Region, North Central Region, and the Trans-Pecos Region may prove to be adapted to the production of certain classes of cement. The Goodland, Comanche Peak, and Edwards limestone of the Comanchean and the Austin Chalk of the Upper Cretaceous lie nearest the center of population. The Austin Chalk is in contact with clay marls both above and below, hence all the materials essential to the manufacture of Portland cement are brought close together in the more densely populated region between Dallas, Sherman and San Antonio. The most logical combination of adjacent formations for the manufacture of cement would be Walnut clay and Edwards or Goodland limestone, Del Rio clay and Georgetown limestone, Eagle Ford shale and Austin Chalk, Taylor marls and Austin Chalk.

There are five Portland cement plants in the State. Two cement plants in the vicinity of Eagle Ford, between Dallas and Fort Worth, utilize Austin chalk mixed with Eagle Ford clay. At San Antonio, Austin chalk is used for both natural and Portland cements. At El Paso the Comanchean is used. A plant now being built near Houston will utilize oyster and other molluscan shells of the Gulf.

Sand and Gravel

Most of the sand used in Texas belongs to river and stream deposits of Quaternary and Recent age. Sands from the Trinity Comanchean, from the Coastal Plain Tertiary and from the High Plains Tertiary and Quaternary are also utilized. A large amount of gravels used in the State comes from recent stream deposits. Some gravel of Triassic, Tertiary and Quaternary ages is used in the High Plains region. The Trinity gravels are also locally utilized as are the Lafayette gravels, particularly of the Gulf Coastal Plain, where they are the only gravels present. There is a conspicuous lack of good gravel in southeast Texas, where also hard structural materials and materials for the manufacture of cement are very scarce.

Limestone

Limestone suitable for masonry is liberally distributed over the central and western part of the State. The Comanchean limestones are the most abundant. The Edwards and the Georgetown formations can frequently be quarried in large blocks. They also contain some white stone of uniform and fine texture, which is considered an ornamental building stone, when given a smooth ground face. Some quarries in Williamson County have furnished the stone used in the University Library in Austin. The Comanchean limestones are available in the central and the southwestern and western part of the State. As a class, this limestone is not as hard as some other limestones in the State. The Pennsylvanian limestone in the north-central part of the State occurs usually in beds from one to fifty feet thick and is generally more indurated than the Comanchean. Our hardest limestone occurring over considerable territory is the Ellenburger limestone which is of Cambrian-Ordovician age. This formation extends in a broken belt around the Central Mineral Region. In places, as near San Saba, it is a marble of fine texture. When crushed and used as road material, this rock is unsurpassed by any other limestone. The annual production of limestone for building has a value of some $550,000.

Granite

The value of granite produced in the State is estimated at some $3,000,000. The two most important structures built of Texas granite are the State Capitol and the seawall at Galveston. The rock used in these is a coarse red granite. Stone of this kind occurs over large areas in Burnet, Gillespie, Mason, and Llano counties. Other varieties of granite are gray granite and "opaline" granite. The latter is regarded by many as a handsome rock, is very hard and takes a fine polish. It contains numerous inclusions of a bluish quartz in small oval pieces. The gray granite is now quarried in Mason County as well as in Llano County.

Gypsum

The principal production of plaster and stucco in this State is from two factories at Acme in Hardeman County, from whence nearly 1,000,000 tons have so far been shipped. The principal gypsum-bearing formation is the upper red beds of the Permian. The gypsum occurs in layers from 10 to 50 feet in thickness. The gypsum-bearing strata of this formation outcrop in a belt some 50 or more miles wide, extending in a south-southwest direction from north of Hardeman County to Sterling County. To the west from this belt the gypsum-bearing beds dip under later formations and underlie the entire Llano Estacado, where some deep borings have penetrated beds of anhydrite aggregating several hundred feet in thickness. The gypsum appears to have been originally deposited as anhydrite, which by hydration later has been changed to gypsum in the upper 400 or 500 feet from the surface. The same gypsiferous beds are again exposed in the Castile formation in Culberson County, and at some points in Reeves and Pecos counties. East of Finlay some gypsum is quarried from possibly the same

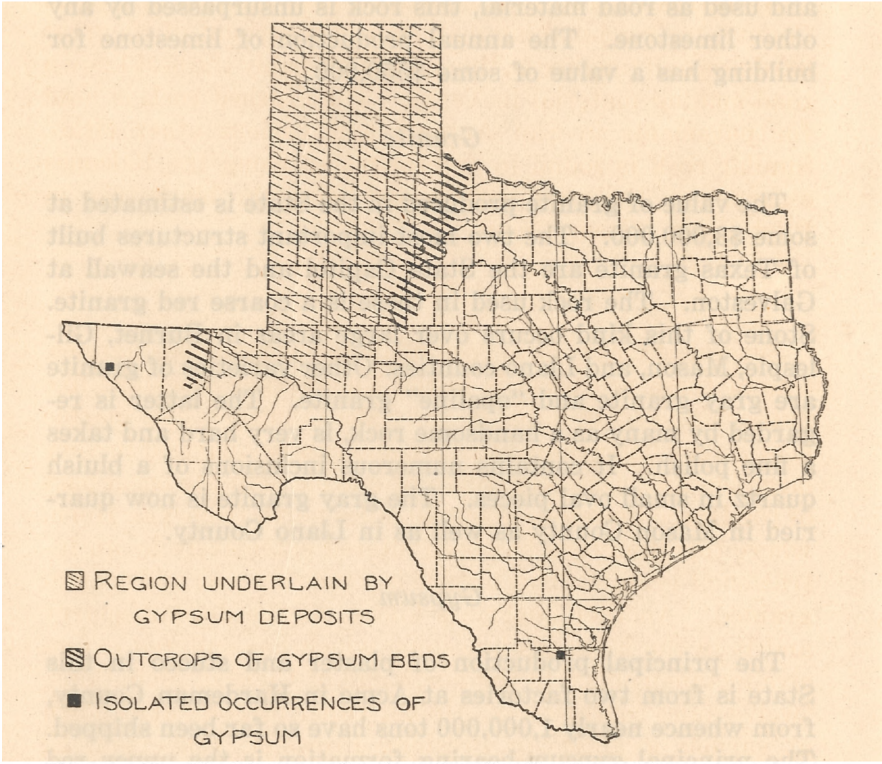

Figure 12.—Sketch map showing the distribution of known gypsum beds in Texas.

formation on the Southern Pacific railroad. Gypsum is also known in several of the salt domes of the coastal oil fields at varying depths below the surface. A single instance of gypsum apparently produced in a structure of this kind is known to be now exposed at points six miles east of Falfurrias, in Brooks County. Some deep holes have been drilled through several hundred feet of this gypsum. It can be easily quarried in an open face 60 feet high. The material is pure enough to be used for any purpose.

Trap Rock

An intrusive trap rock is worked near Knippa in Uvalde County, for road-making material. On account of its great hardness and toughness, this rock is probably the best known road-making material in Texas. The crushed rock is used for pavements in San Antonio and various other cities. Similar rock is found in several places along the Balcones escarpment, the most notable one being the black trap in Pilot Knob, Travis County.

Marble

Several attempts have been made to open marble quarries. One of these prospects is in the Ellenburger limestone five miles south of San Saba, in San Saba County. This marble is of a very fine-grained texture and can be quarried in very large blocks. One occurrence of marble is in the basal part of the Hueco limestone about 40 miles north from Van Horn, where this limestone has been altered extensively by an intrusion of granite. This marble is somewhat soft and coarse-grained. Another quarry is known as the Jordan quarry and is in the Edwards limestone which has suffered extensive metamorphism in the north end of Cienega Mountains, twelve miles southwest of Alpine. Other marbles are known at various localities in Presidio, Brewster, Culberson, El Paso, Mason, and Llano counties.

Sandstone

Some sandstone has been quarried from rocks of nearly all ages represented in the State. At Barstow in Ward County a red sandstone was quarried which has been quite extensively shipped to many parts of the State. It is generally used for trimmings in brick and stone buildings. This rock is of Permian age.

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